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Maeda et al.

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(45) **Date of Patent: Jul. 14, 2015**

(54) **INFORMATION PROCESSING DEVICE, VIRTUAL MACHINE CREATION METHOD, AND APPLICATION DISTRIBUTION SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 360 days.

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G06F 9/455 (2006.01)
G06F 9/48 (2006.01)
G06F 21/53 (2013.01)

(52) **U.S. Cl.**
CPC ***G06F 9/45533*** (2013.01); ***G06F 9/4843*** (2013.01); ***G06F 21/53*** (2013.01); *G06F 2009/45562* (2013.01); *G06F 2009/45587* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Camquy Truong
Assistant Examiner — Mehran Kamran
(74) *Attorney, Agent, or Firm* — Wenderoth, Lind & Ponack, L.L.P.

(57) **ABSTRACT**

A device (**110**) according to an implementation of the present invention, having a plurality of virtual machines (**1002**, **1003**, **1004**, and **1005**), includes a virtualization software (**1001**) which manages the virtual machines. The virtualization software includes an application VM creating unit (**1300**) which creates a virtual machine for executing a program. A first virtual machine (**1002**) determines whether a first program is to be executed on the first virtual machine or to be executed on a virtual machine other than the first virtual machine. When the first virtual machine determines that the first program is to be executed on the other virtual machine, the application VM creating unit creates a second virtual machine for executing the first program.

13 Claims, 25 Drawing Sheets

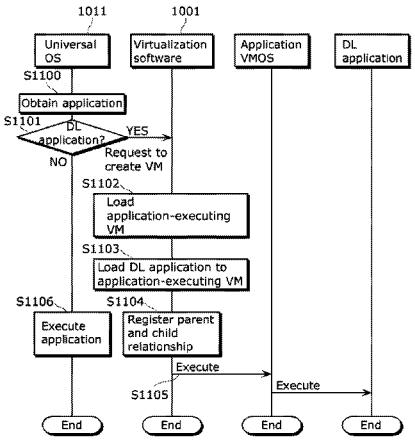

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FIG. 1

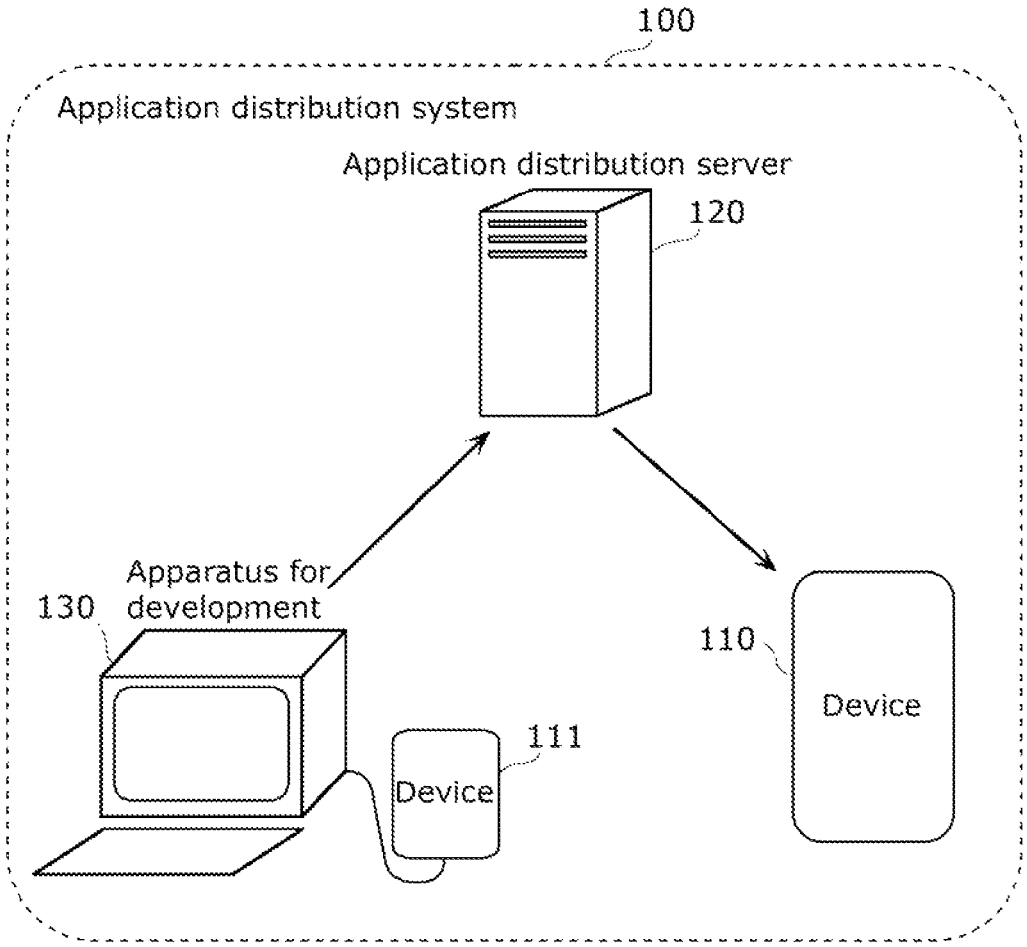

100
Application distribution system
Application distribution server
120
Apparatus for development
130
110
Device
111
Device

FIG. 2

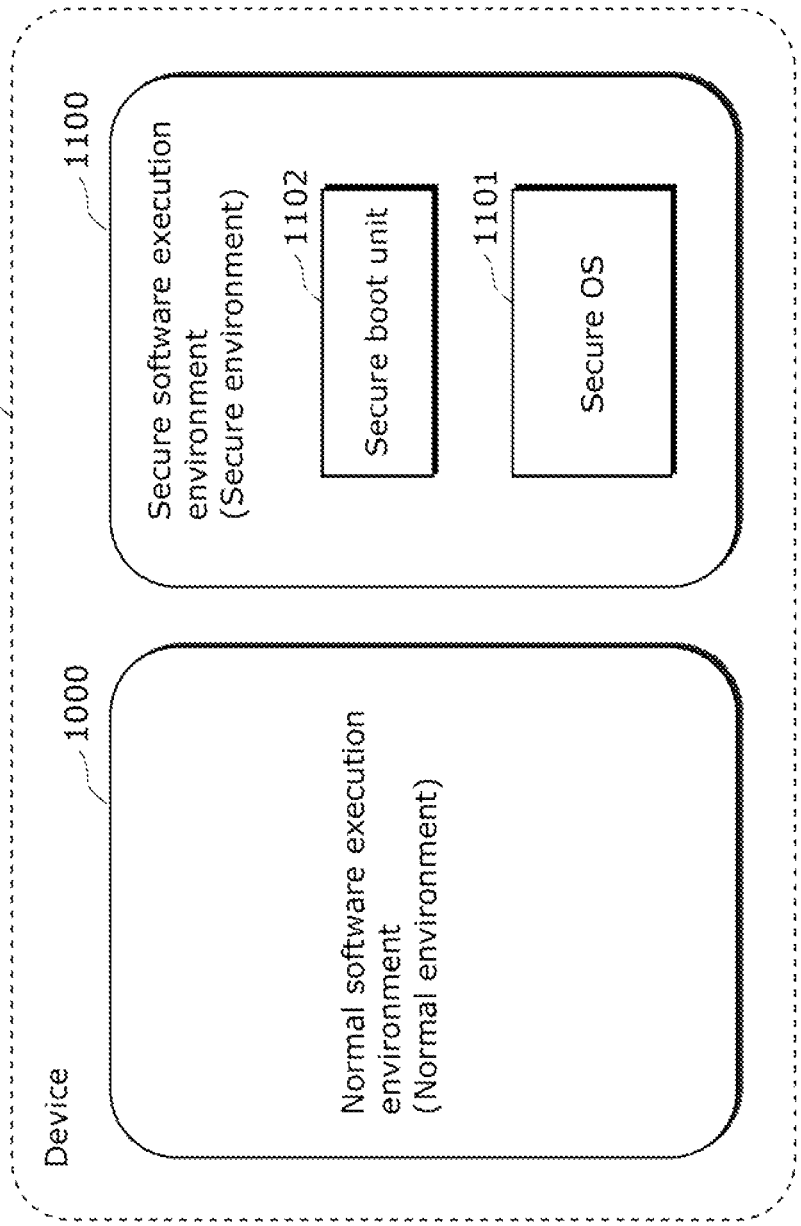

110, 111
Device
1000
Normal software execution environment (Normal environment)
1100
Secure software execution environment (Secure environment)
1102
Secure boot unit
1101
Secure OS

FIG. 3

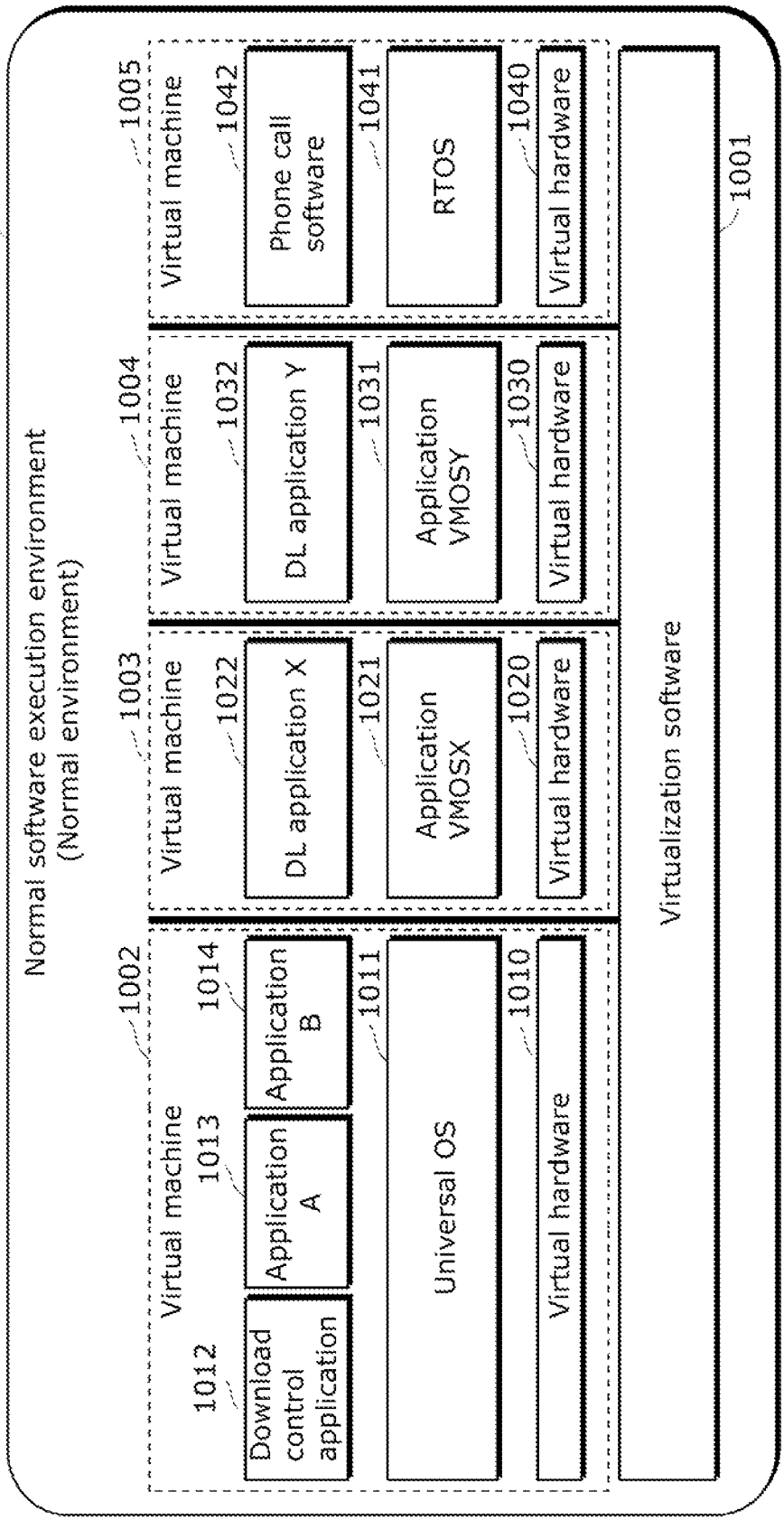

1000
Normal software execution environment
(Normal environment)
1001
Virtualization software
1002
Virtual machine
1012
Download control application
1013
Application A
1014
Application B
1011
Universal OS
1010
Virtual hardware
1003
Virtual machine
1022
DL application X
1021
Application VMOSX
1020
Virtual hardware
1004
Virtual machine
1032
DL application Y
1031
Application VMOSY
1030
Virtual hardware
1005
Virtual machine
1042
Phone call software
1041
RTOS
1040
Virtual hardware

FIG. 4

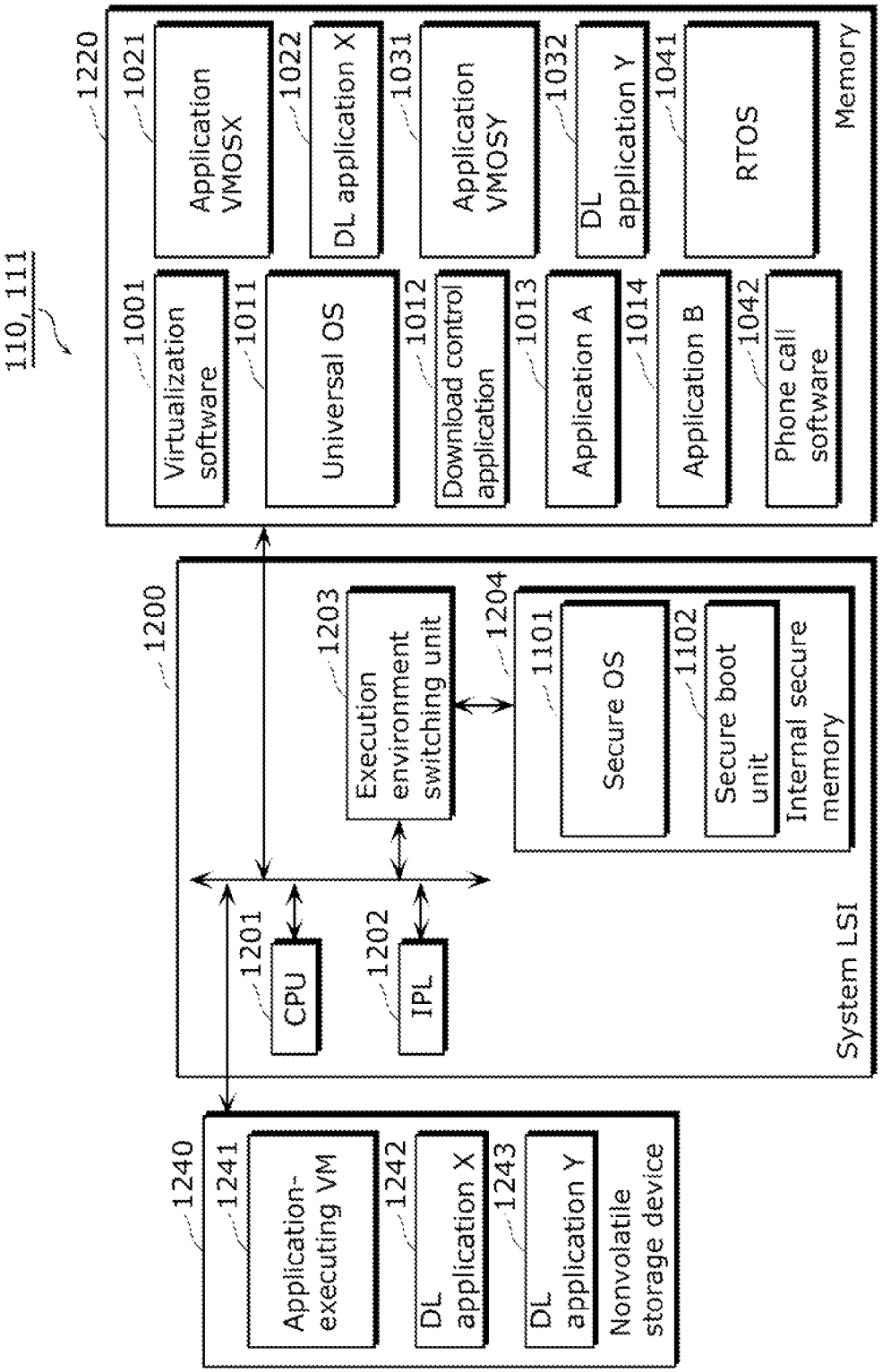

110, 111
1220
Memory
1021
Application VMOSX
1022
DL application X
1031
Application VMOSY
1032
DL application Y
1041
RTOS
1001
Virtualization software
1011
Universal OS
1012
Download control application
1013
Application A
1014
Application B
1042
Phone call software
1200
System LSI
1203
Execution environment switching unit
1204
1101
Secure OS
1102
Secure boot unit
Internal secure memory
1201
CPU
1202
IPL
1240
Nonvolatile storage device
1241
Application-executing VM
1242
DL application X
1243
DL application Y

FIG. 5

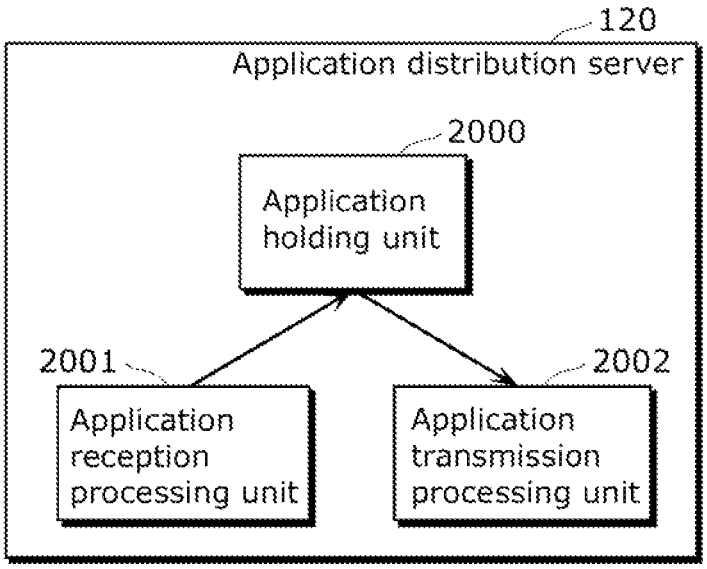

120
Application distribution server
2000
Application holding unit
2001
Application reception processing unit
2002
Application transmission processing unit

FIG. 6

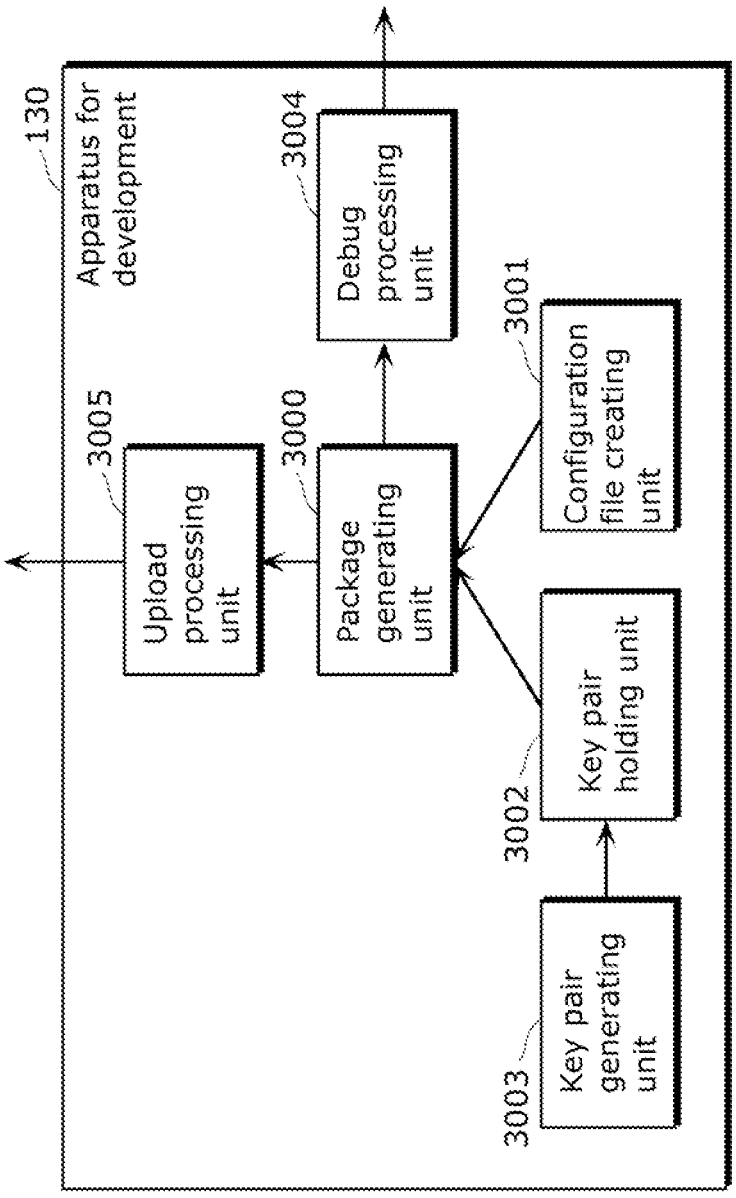

130
Apparatus for development
3004
Debug processing unit
3001
Configuration file creating unit
3005
Upload processing unit
3000
Package generating unit
3002
Key pair holding unit
3003
Key pair generating unit

FIG. 7

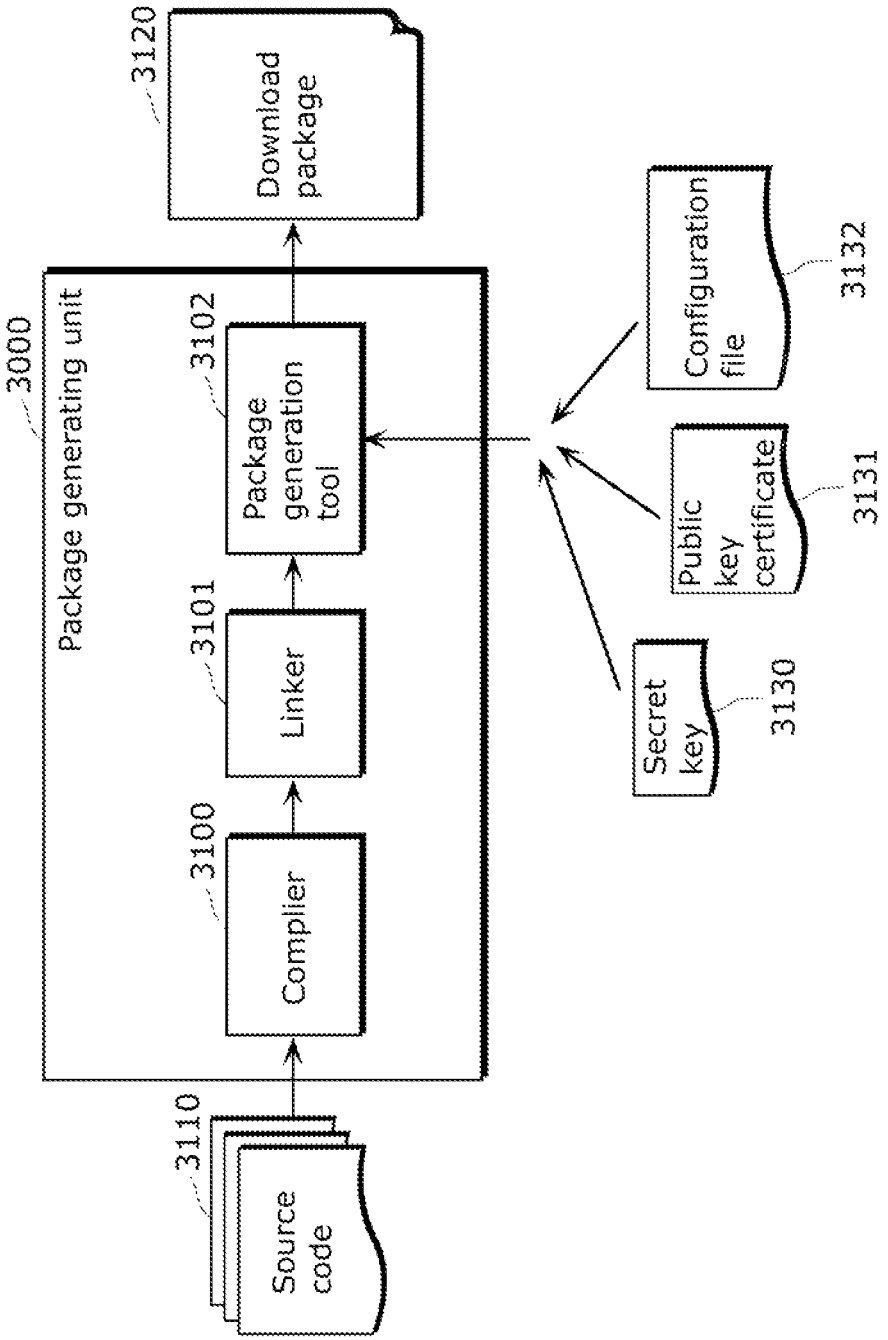

3120
Download package
3000
Package generating unit
3102
Package generation tool
3101
Linker
3100
Complier
3110
Source code
Configuration file
3132
Public key certificate
3131
Secret key
3130

FIG. 8

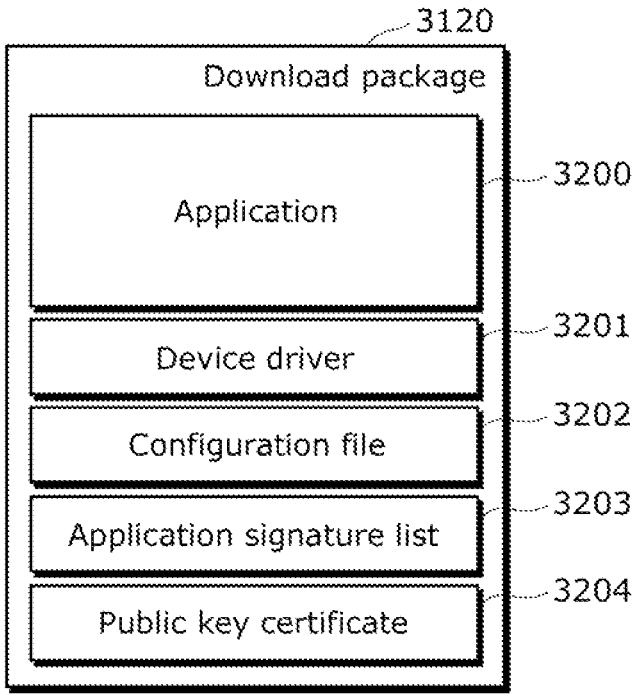

3120
Download package
Application
3200
Device driver
3201
Configuration file
3202
Application signature list
3203
Public key certificate
3204

FIG. 9

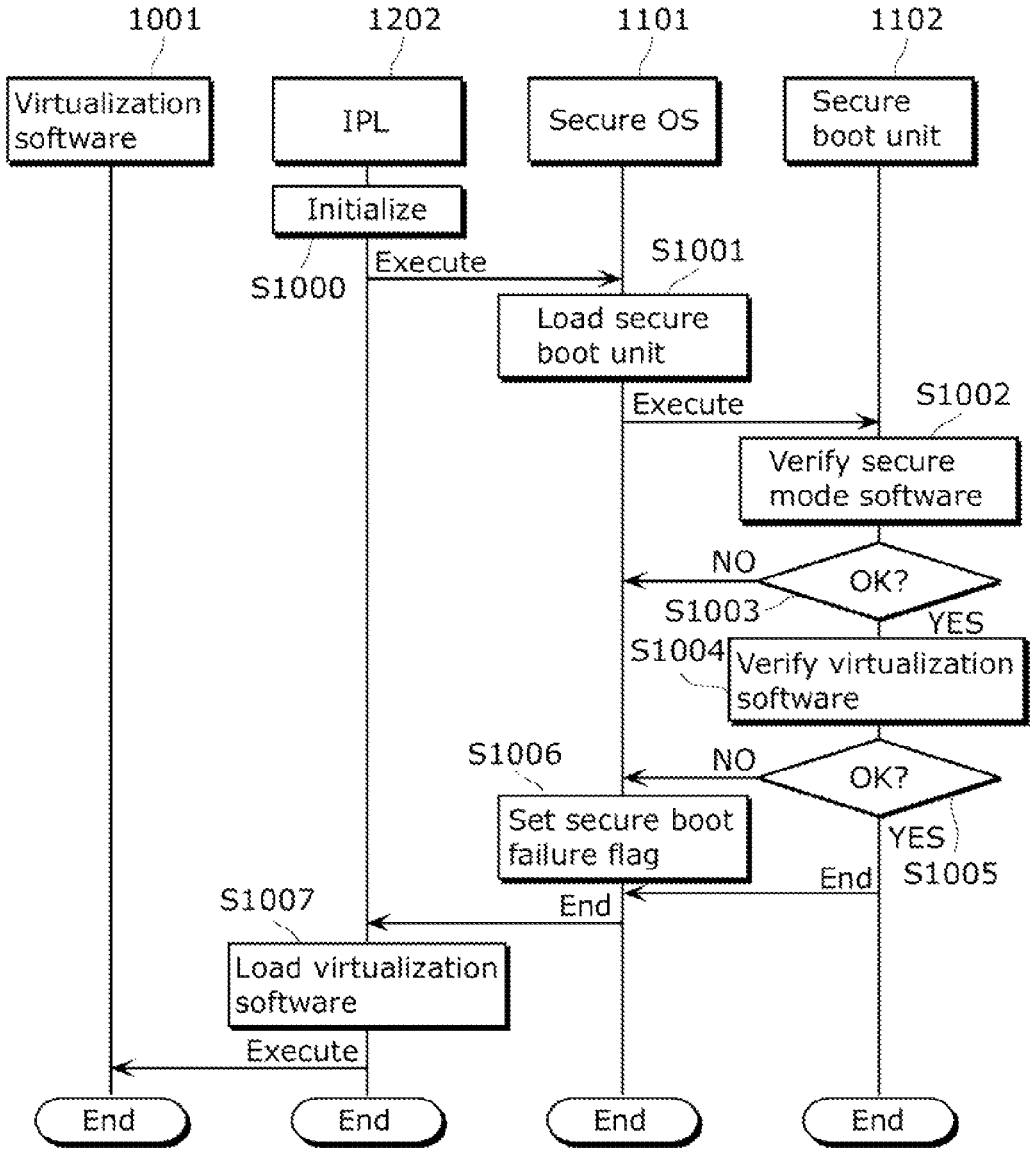

1001
1202
1101
1102
Virtualization software
IPL
Secure OS
Secure boot unit
Initialize
S1000
Execute
S1001
Load secure boot unit
Execute
S1002
Verify secure mode software
NO
OK?
S1003
YES
S1004
Verify virtualization software
S1006
NO
OK?
Set secure boot failure flag
YES
S1005
End
End
S1007
Load virtualization software
Execute
End
End
End
End

FIG. 10

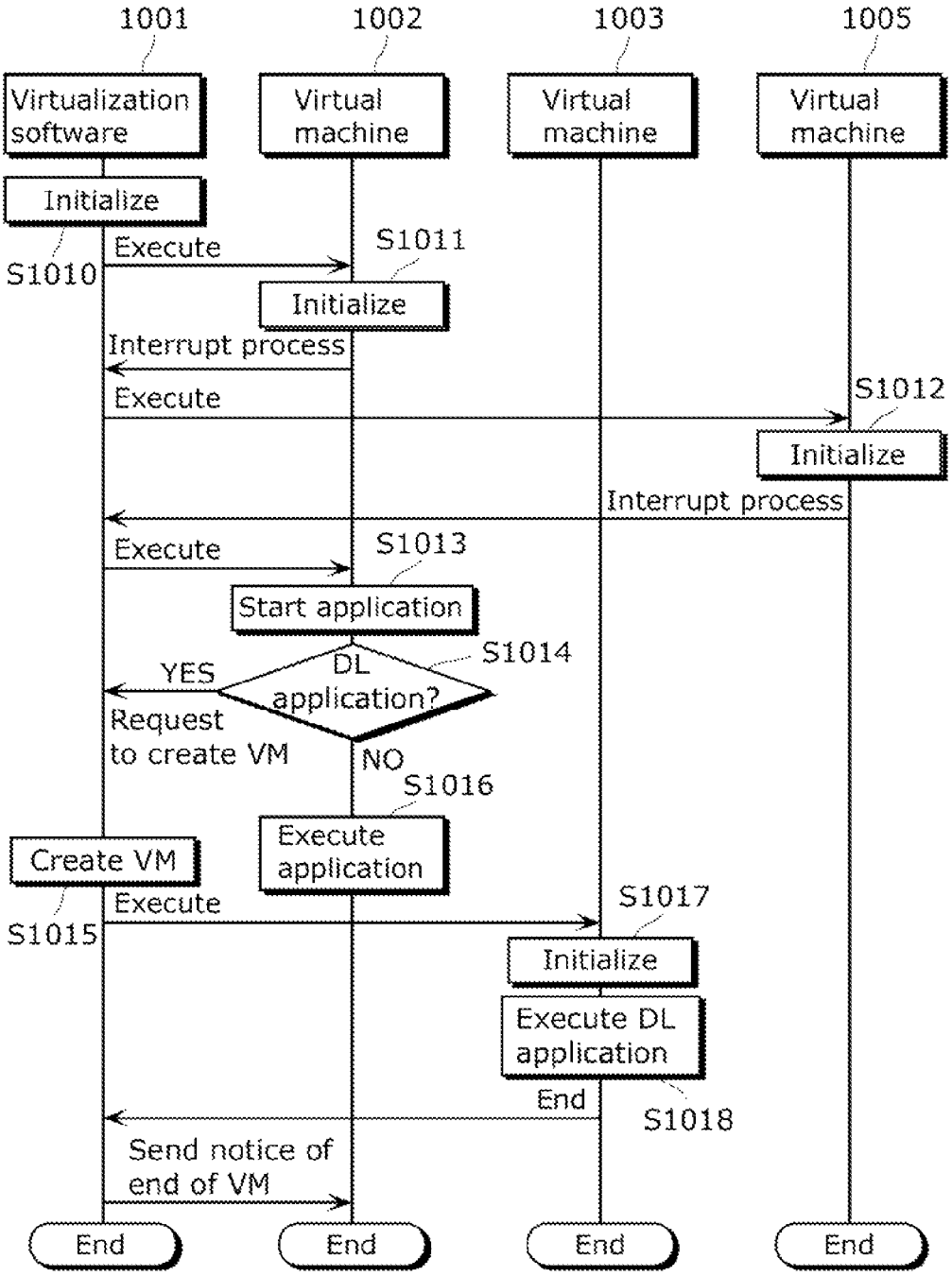

1001
1002
1003
1005
Virtualization software
Virtual machine
Virtual machine
Virtual machine
Initialize
S1010
Execute
S1011
Initialize
Interrupt process
Execute
S1012
Initialize
Interrupt process
Execute
S1013
Start application
S1014
DL application?
YES
Request to create VM
NO
S1016
Execute application
Create VM
S1015
Execute
S1017
Initialize
Execute DL application
S1018
End
Send notice of end of VM
End
End
End
End

FIG. 11

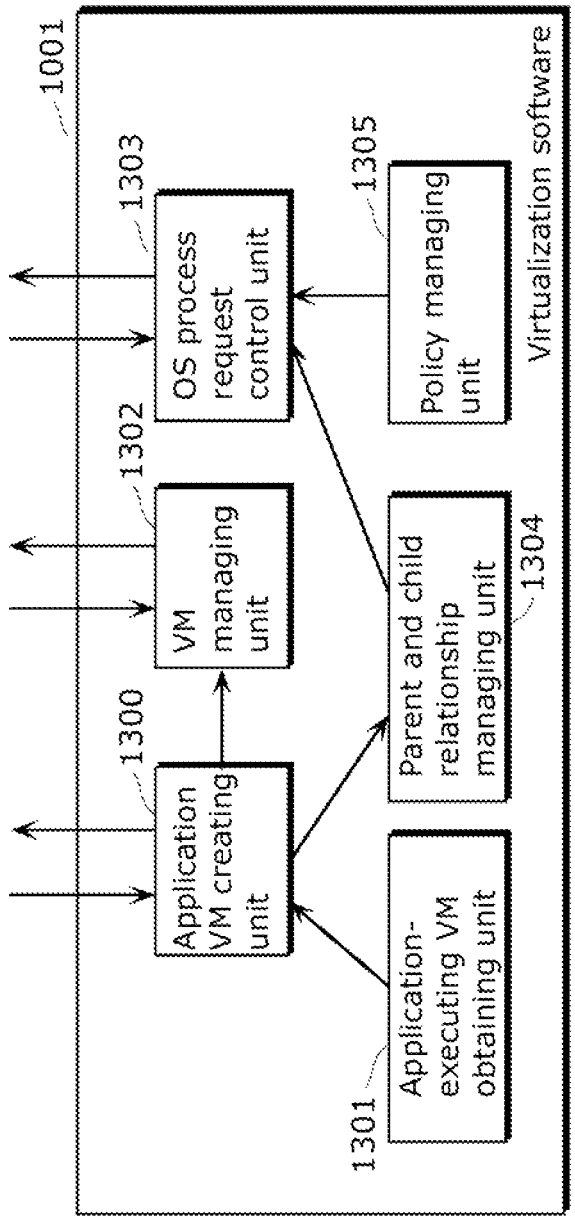

1001
Virtualization software
1300
Application VM creating unit
1301
Application-executing VM obtaining unit
1302
VM managing unit
1303
OS process request control unit
1304
Parent and child relationship managing unit
1305
Policy managing unit

FIG. 12

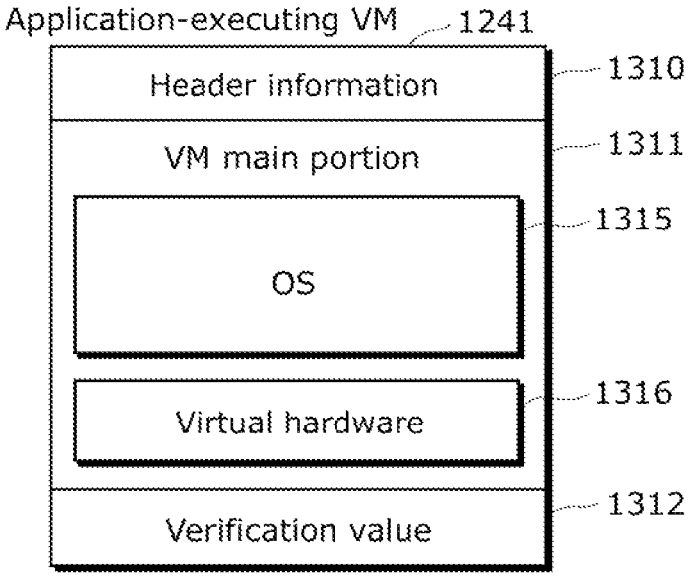


FIG. 13

1350

ID	Status	Memory	Destination for storing suspension state
1	Running	0x52000 - 0x62000	0x10000
....	....	....	....
n	Suspended	0xA0000 - 0xB0000	0x10500

FIG. 14

1360

Parent virtual machine ID	Child virtual machine ID
1	3
1	4
....	....
2	5

FIG. 15A

1370

Function	Virtual machine ID
TV viewing	1
Phone call	2
....	....
Play back of commercial content	0

FIG. 15B

1371

Function	Virtual machine 1	Virtual machine 2	....	Virtual machine m
TV viewing	Yes	No	....	No
....	....	....	....	....
Play back of commercial content	No	Yes	....	No

FIG. 16

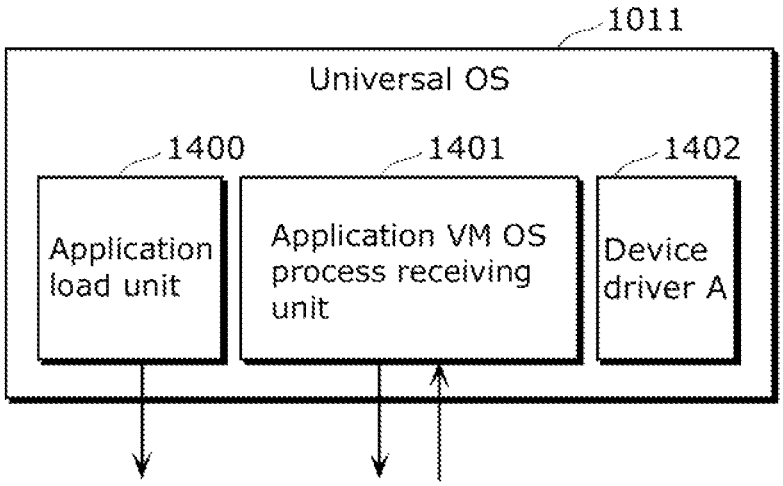


FIG. 17A

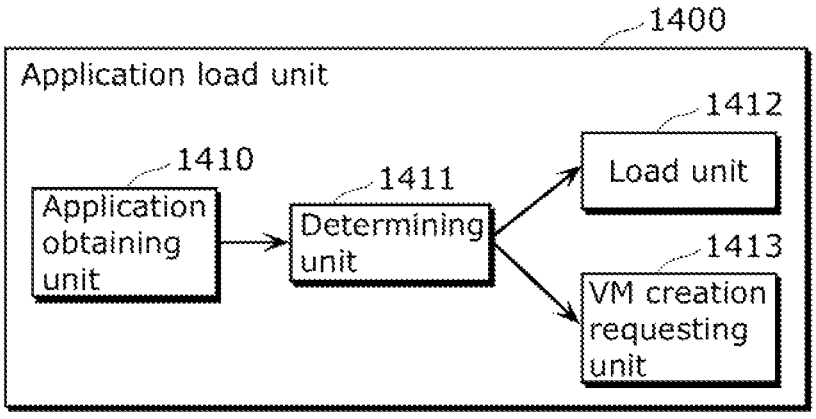


FIG. 17B

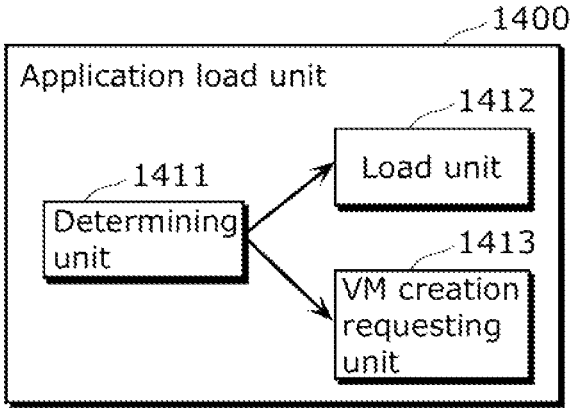


FIG. 18A

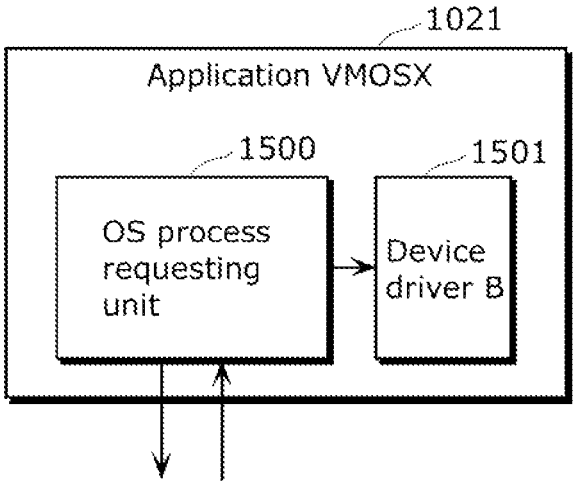


FIG. 18B

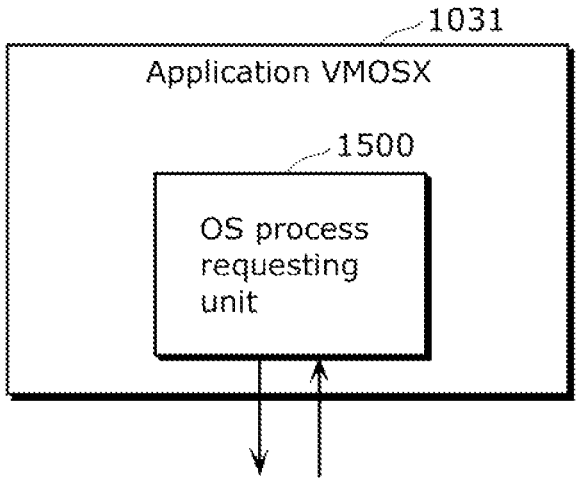


FIG. 19A

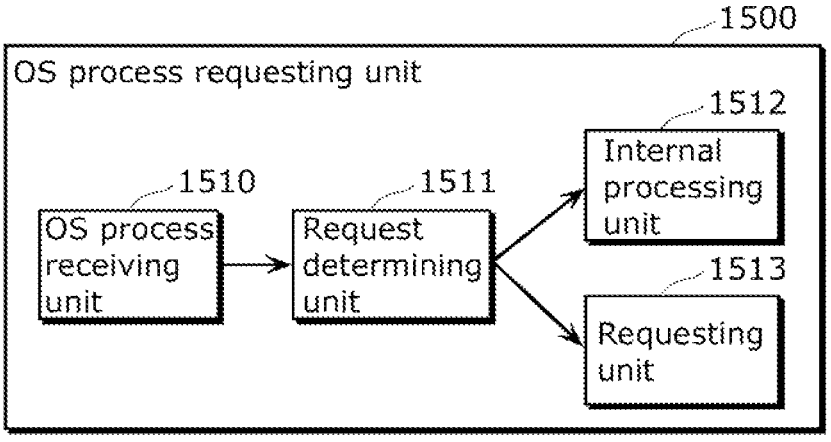


FIG. 19B

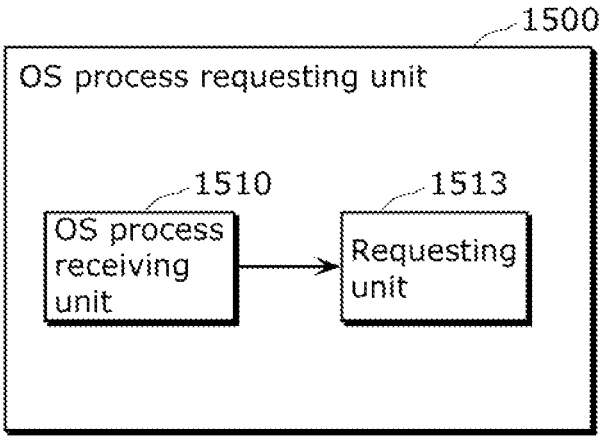

1500
OS process requesting unit
1510
OS process receiving unit
1513
Requesting unit

FIG. 20

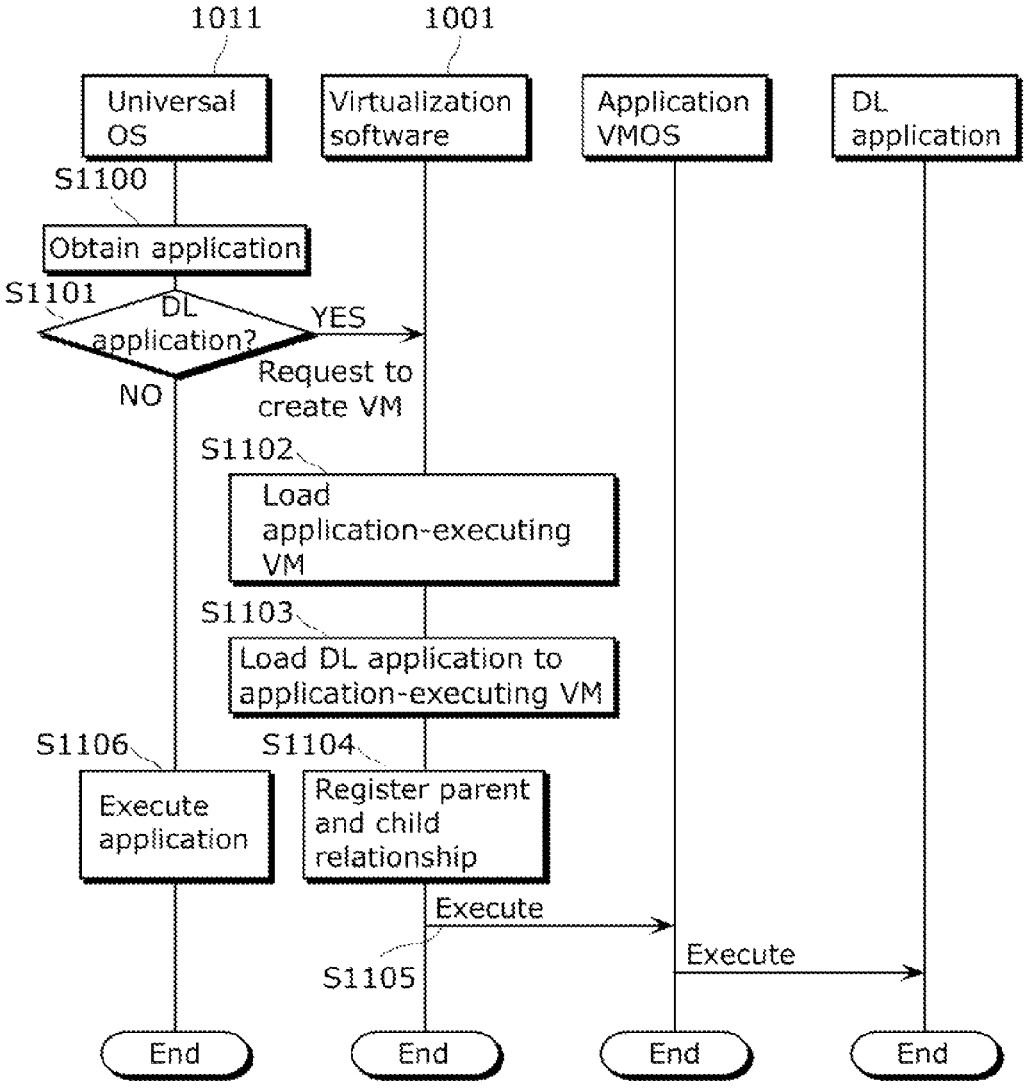

1011
1001
Universal OS
Virtualization software
Application VMOS
DL application
S1100
Obtain application
S1101
DL application?
YES
Request to create VM
NO
S1102
Load application-executing VM
S1103
Load DL application to application-executing VM
S1106
S1104
Execute application
Register parent and child relationship
Execute
S1105
Execute
End
End
End
End

FIG. 21

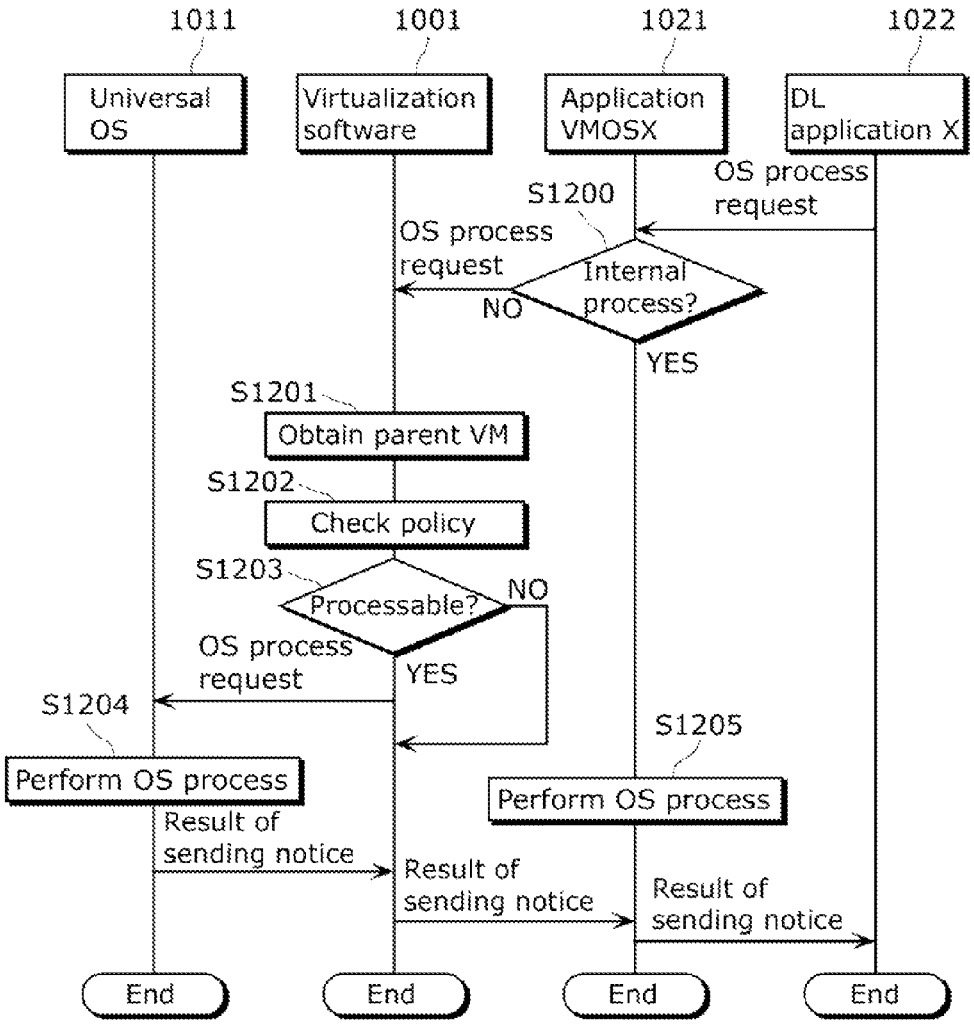

1011
1001
1021
1022
Universal OS
Virtualization software
Application VMOSX
DL application X
OS process request
S1200
OS process request
Internal process?
NO
YES
S1201
Obtain parent VM
S1202
Check policy
S1203
Processable?
NO
OS process request
YES
S1204
S1205
Perform OS process
Perform OS process
Result of sending notice
Result of sending notice
Result of sending notice
End
End
End
End

FIG. 22

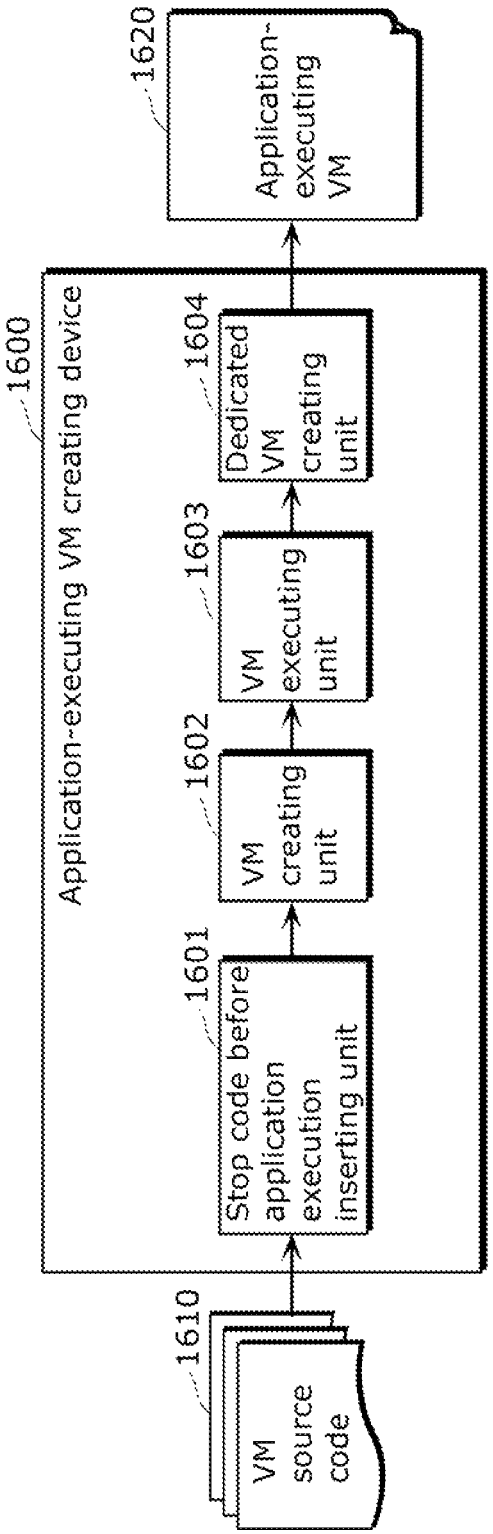

1620
Application-executing VM
1600
Application-executing VM creating device
1604
Dedicated VM creating unit
1603
VM executing unit
1602
VM creating unit
1601
Stop code before application execution inserting unit
1610
VM source code

FIG. 23

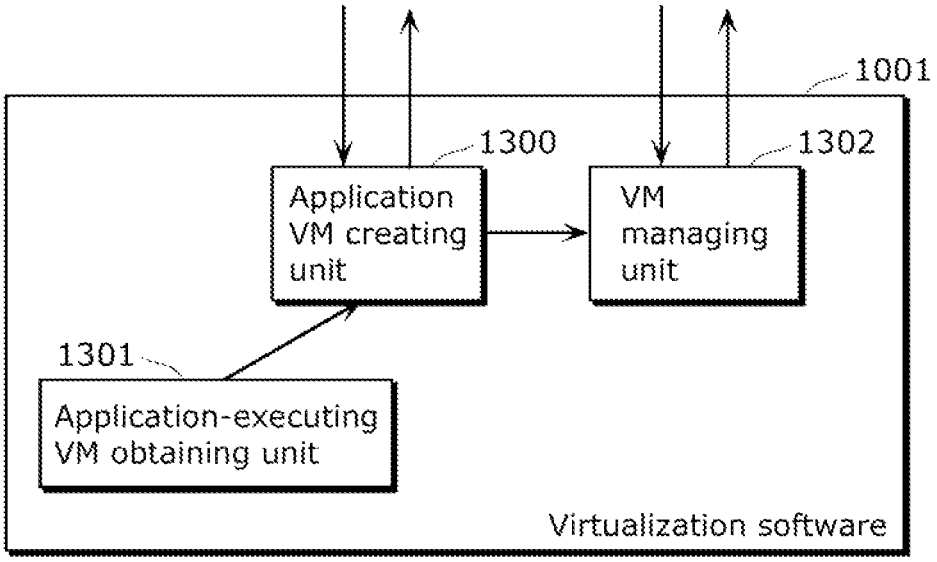

1001
1300
1302
Application VM creating unit
VM managing unit
1301
Application-executing VM obtaining unit
Virtualization software

FIG. 24

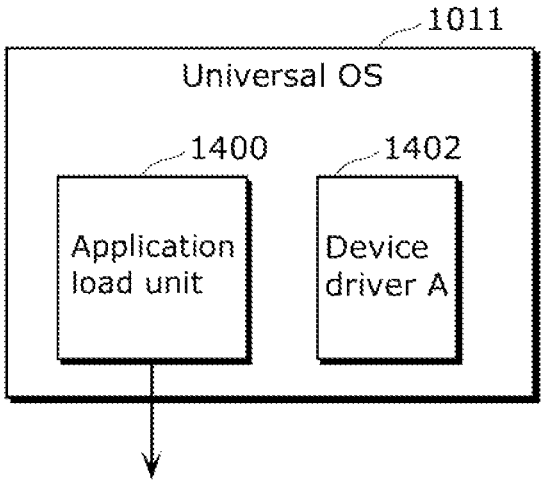

1011
Universal OS
1400
1402
Application load unit
Device driver A

FIG. 25

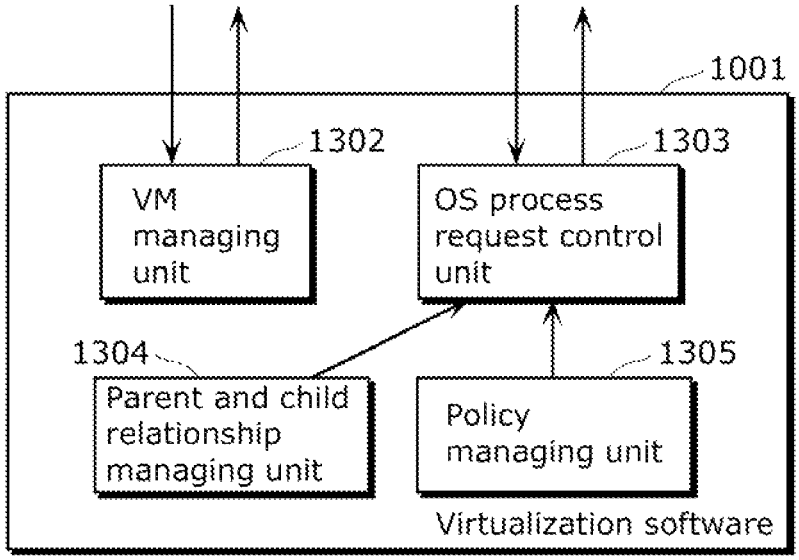

1001
1302
1303
VM managing unit
OS process request control unit
1304
1305
Parent and child relationship managing unit
Policy managing unit
Virtualization software

FIG. 26

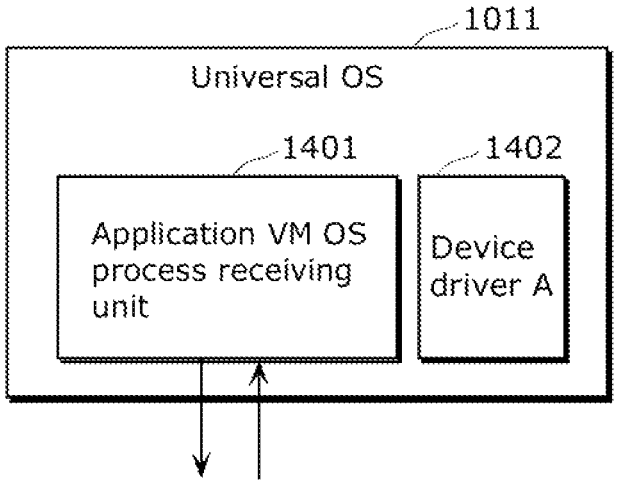

1011
Universal OS
1401
1402
Application VM OS process receiving unit
Device driver A

FIG. 27

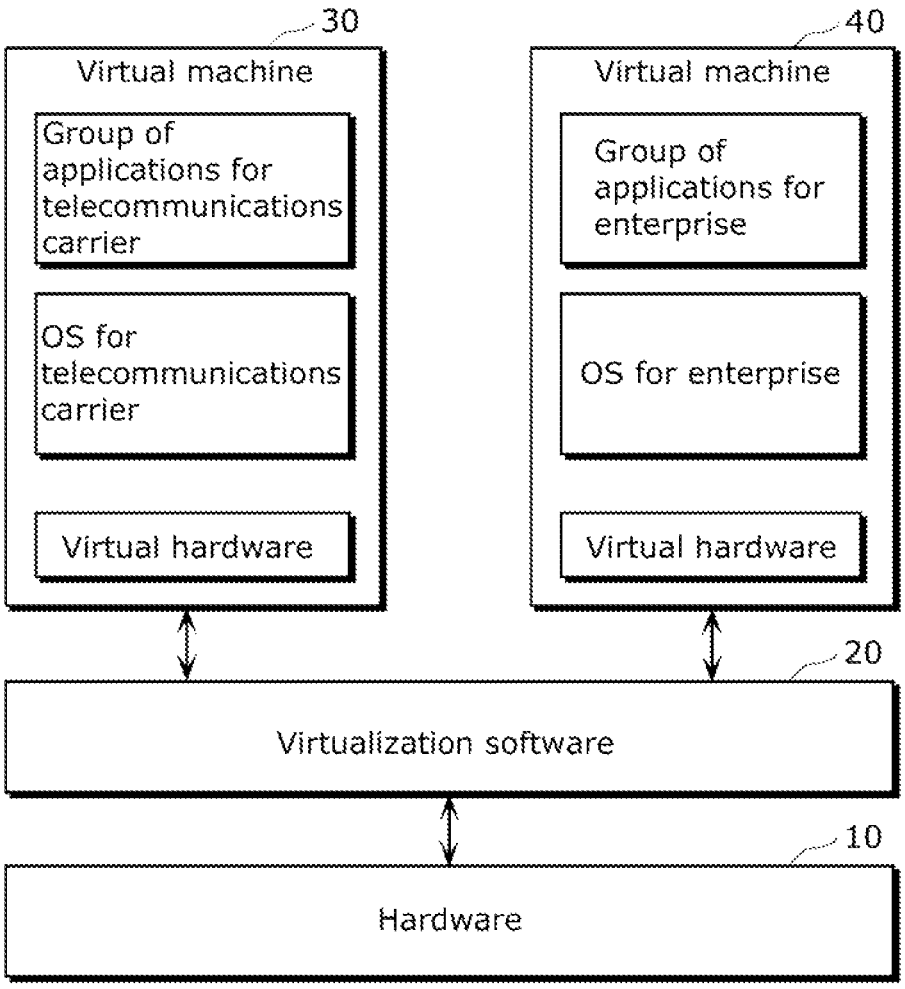
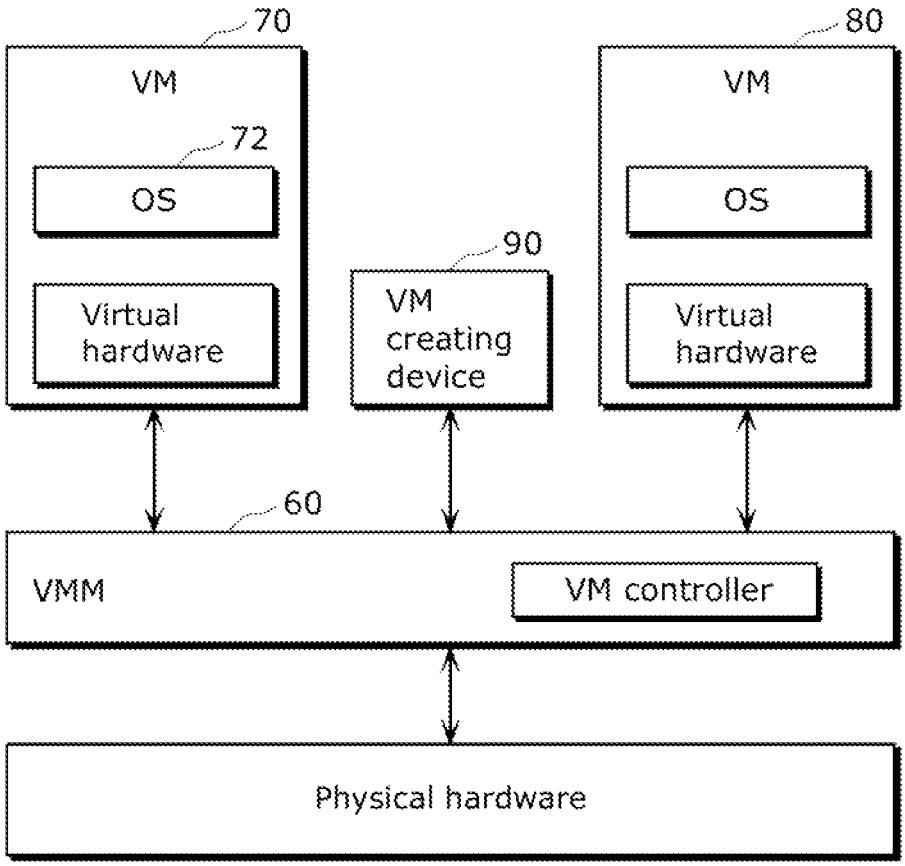

30
Virtual machine
Group of applications for telecommunications carrier
OS for telecommunications carrier
Virtual hardware
40
Virtual machine
Group of applications for enterprise
OS for enterprise
Virtual hardware
20
Virtualization software
10
Hardware

FIG. 28


70
VM
72
OS
Virtual hardware
90
VM creating device
80
VM
OS
Virtual hardware
60
VMM
VM controller
Physical hardware

INFORMATION PROCESSING DEVICE, VIRTUAL MACHINE CREATION METHOD, AND APPLICATION DISTRIBUTION SYSTEM

TECHNICAL FIELD

The present invention relates to an information processing device, a virtual machine creation method, and an application distribution system which prevent unauthorized access to data.

BACKGROUND ART

Conventional TVs and cellular phones allow users to download application software (hereafter referred to as "application") so as to add a new function after the purchase of a device (a TV or cellular phone), and use the application software. Access by such an application to various resources in the device is limited conventionally. Here, examples of the resources in the device include position information such as GPS (Global Positioning System), and data generated by another application such as a dial function, an address book, a bookmark, and image data. However, in recent years, the access limitation has been eased to allow the development of a variety of applications, and devices which allow access to the position information and the data such as the dial function and the address book have become available. In the future, it is considered that devices which allow the users to install device driver software (hereafter referred to as "device driver") so as to add new hardware would become available.

Moreover, only the specific application development companies conventionally develop and distribute the applications. However, in recent years, a system is being developed in which general users can develop and distribute applications. In such a system, in order for the general users to easily develop applications, development tools generally used in a personal computer (hereafter referred to as "PC") are available for the development of applications, and debuggers can be connected to devices for sale.

At the same time, the leakage of data such as personal information stored in the PC, the cellular phone, or the like has become a problem. Especially in the PC, malicious software which is downloaded from an open network such as the Internet reads the data such as the personal information or the like stored in a storage device of the PC, and transmits the data to outside of the PC via the network despite a user's intention. Moreover, the malicious software causes a user to download the malicious software by making, with the use of an email or the like, the user believe that the malicious software itself is a useful software for the user, or by exploiting the vulnerability of software which operates on the PC.

In particular, a device driver can access data deployed by an application on a memory. For this reason, a device driver in a device to which the device driver can be installed accesses data that is undesirable to be disclosed to another application such as the personal information, and thus the device has a high risk of the leakage.

In such a manner, the downloaded application (hereafter referred to as "DL application") and the downloaded device driver (hereafter referred to as "DL device driver") can access many resources in the PC, the TV, and the cellular phone. Moreover, the general users can develop and distribute applications and device drivers, which increases the threat of attacks against the personal information stored in the device. Specifically, such a situation makes it easier for malicious attackers to develop and install attack applications (hereafter referred to as "malicious applications") and attack device drivers (hereafter referred to as "malicious device drivers"). This enables the malicious applications and the malicious device drivers to access information in the device, which increases the danger of the leakage and tampering of information.

There has conventionally been a method of separating execution environments in each of which a software is executed, as a method of protecting, from a DL application and a DL device driver, an original function of a device such as a telephone function in a cellular phone (see NPL 1, for example). NPL 1 discloses, as the method of separating execution environments, a method of separating execution environments using a CPU having a plurality of modes such as a normal mode and a secure mode, and a method of separating execution environments using a virtualization technology. FIG. **27** is a diagram showing the conventional method of separating execution environments using a virtualization technology which is disclosed by NPL 1.

In FIG. **27**, a virtual machine **30** executes an operating system (hereafter referred to as "OS") and an application which are selected and developed by, for example, a telecommunications carrier of cellular phone. A virtual machine **40** executes applications for providing, by an enterprise other than the telecommunications carrier, a schedule and email service for workers of the enterprise. A virtualization software **20** provides, for the virtual machines **30** and **40**, a virtual hardware function obtained by virtualizing a hardware **10**. In addition, the virtualization software **20** controls the operations of the virtual machines **30** and **40**.

The configuration shown in FIG. **27** makes it possible to separate the virtual machine **30** which provides a communication function that is the basic function of the cellular phone and the virtual machine **40** which provides the service for the workers, in addition to the OS.

Consequently, the malicious application or the malicious device driver does not influence the applications and the OS of the telecommunications carrier which operate on the virtual machine **30**, even when, for example, the virtual machine **40** has a function which allows the user to freely download applications and device drivers and the malicious application or the malicious device driver operates on the virtual machine **40**.

Furthermore, there is a method of dynamically creating a virtual machine using a VM creating device as a method of causing a virtual machine providing additional service for a device such as the virtual machine **40** to operate when needed (see PLT 1, for example). FIG. **28** is a block diagram showing a conventional virtual machine creating system described in PTL 1.

In FIG. **28**, an OS **72** requests a VMM (virtual machine manager) **60** to create a virtual machine. As a result, a VM creating device **90** creates a virtual machine **80**. Upon the creation, the virtual machine **80** becomes a copy of a virtual machine **70** at the time when the OS **72** requests the creation of the virtual machine.

CITATION LIST

Patent Literature

[PTL 1]
Japanese Unexamined Patent Application Publication No. 2008-165795
[PTL 2]
Japanese Unexamined Patent Application Publication No. 2005-011336

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SUMMARY OF INVENTION

Technical Problem

However, with the conventional configurations, downloaded applications and device drivers operate in the same virtual machine. Thus, the conventional configurations do not make it possible to secure other downloaded applications when a malicious application or a malicious device driver is downloaded.

The present invention has been conceived to solve the conventional problem, and an object of the present invention is to provide an information processing device which makes it possible to prevent the malicious application or the malicious device driver from accessing information in the other applications.

Solution to Problem

In order to solve the conventional problem, an information processing device according to an aspect of the present invention is an information processing device which has a plurality of virtual machines and includes a virtual machine managing unit which manages the virtual machines. The virtual machine managing unit includes an application virtual machine (VM) creating unit which creates a virtual machine for executing a program. A first virtual machine determines whether a first program is to be executed on the first virtual machine or to be executed on a virtual machine other than the first virtual machine, the first virtual machine being one of the virtual machines, and the first program being executable on the first virtual machine. When the first virtual machine determines that the first program is to be executed on the other virtual machine, the application VM creating unit creates a second virtual machine for executing the first program.

With this configuration, the information processing device according to the aspect of the present invention creates a virtual machine independent of an application that may be an attack application (malicious application or malicious device driver) of a malicious attacker, and allows the virtual machine to execute the application. As a result, the information processing device successfully prevents the application from accessing the information held by other applications.

Moreover, when the first program is a program obtained from an other device, the first virtual machine may determine that the first program is to be executed on the other virtual machine.

With this configuration, the information processing device according to the aspect of the present invention successfully prevents the application that may be the malicious application or the malicious device driver and is obtained from the other device from accessing the information held by the other applications.

Moreover, when the first program includes a device driver software program obtained from an other device, the first virtual machine may determine that the first program is to be executed on the other virtual machine.

With this configuration, the information processing device according to the aspect of the present invention successfully prevents the malicious device driver from accessing the information held by the other applications.

Moreover, the information processing device may further include a storage unit which stores an operating system (OS) program for VM. The first virtual machine may further determine whether a second program is to be executed on the first virtual machine or to be executed on the other virtual machine, the second program being different from the first program and executable on the first virtual machine. The application VM creating unit may (i) create a third virtual machine for executing the second program, when the first virtual machine determines that the second program is to be executed on the other virtual machine, and (ii) create, using the OS program for VM, an operating system for the second virtual machine and an operating system for the third virtual machine.

With this configuration, the information processing device according to the aspect of the present invention is capable of using the common OS for the virtual machines. As a result, in comparison with a case where a different OS is used for each virtual machine, it is possible to reduce the capacity of the storage unit more.

Moreover, the second virtual machine may include an OS process requesting unit which sends, to the virtual machine managing unit, an OS process request for the other virtual machine to execute an OS process that is inexecutable on an operating system for the second virtual machine, and the virtual machine managing unit may further include an OS process request control unit which requests the other virtual machine to execute the OS process when the virtual machine managing unit receives the OS process request from the second virtual machine.

With this configuration, in the information processing device according to the aspect of the present invention, the virtual machine can request the other virtual machine to execute the process that the virtual machine cannot execute. Consequently, the function of the OS of each function can be eliminated, and thus a resource (e.g. memory) necessary for each virtual machine can be eliminated.

Moreover, the virtual machine managing unit may further include a parent and child relationship managing unit which manages a parent and child relationship of the virtual machines. The parent and child relationship managing unit may manage a parent and child relationship in which the first virtual machine that requests the creation of the second virtual machine is a parent and the second virtual machine created according to the request is a child. The OS process request control unit may request the first virtual machine to execute the OS process, when the virtual machine managing unit receives the OS process request from the second virtual machine, the first virtual machine being managed as the parent of the second virtual machine.

With this configuration, the information processing device according to the aspect of the present invention is capable of requesting the virtual machine to execute the OS process, the virtual machine being the "parent" of the virtual machine which has sent the OS process request.

Moreover, the virtual machine managing unit may further include a policy managing unit which determines, for each of functions achieved through the OS process request, whether or not it is possible to request the other virtual machine to execute an OS process corresponding to the function. The OS process request control unit may request the first virtual machine to execute the OS process, when the policy managing unit determines that it is possible to request the other virtual machine to execute the OS process.

With this configuration, the information processing device according to the aspect of the present invention successfully prevents the malicious application or the malicious device driver from accessing information held by other applications which achieve specific functions.

Moreover, the OS process requesting unit may (i) determine that the second virtual machine executes the OS process, when the first program includes the device driver software program obtained from the other device and the device driver software program can execute the OS process, and (ii) send the OS process request to the virtual machine managing unit when the device driver software program cannot execute the OS process.

With this configuration, the information processing device according to the aspect of the present invention can eliminate the function of the OS of each virtual machine, and can thus eliminate the resource (e.g. memory) necessary for each virtual machine.

It is to be noted that the present invention is realized not only as such an information processing device but also as a virtual machine creation method having, as steps, the characteristics units included in the information processing device and a program causing a computer to execute such characteristics steps. It goes without saying that such a program can be distributed via a recording medium such as a CD-ROM and a transmission medium such as the Internet.

Furthermore, the present invention can be realized not only as a semiconductor integrated circuit (LSI) which achieves part or all of the functions of the information processing device but also as an application distribution system including the information processing device.

Advantageous Effects of Invention

From the above, the present invention successfully provides the information processing device which prevents the malicious application or the malicious device driver from accessing the information in the other applications.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic diagram showing a whole application distribution system according to Embodiment 1 of the present invention.

FIG. **2** is a software configuration diagram for devices according to Embodiment 1 of the present invention.

FIG. **3** is a schematic diagram showing a normal software execution environment according to Embodiment 1 of the present invention.

FIG. **4** is a hardware configuration diagram of each of devices according to Embodiment 1 of the present invention.

FIG. **5** is a block diagram showing an application distribution server according to Embodiment 1 of the present invention.

FIG. **6** is a block diagram showing a development environment according to Embodiment 1 of the present invention.

FIG. **7** is a block diagram showing a package generating unit according to Embodiment 1 of the present invention.

FIG. **8** is a diagram showing a download application package according to Embodiment 1 of the present invention.

FIG. **9** is a flow chart for secure boot according to Embodiment 1 of the present invention.

FIG. **10** is a flow chart for virtual machine start-up according to Embodiment 1 of the present invention.

FIG. **11** is a block diagram showing a virtualization software according to Embodiment 1 of the present invention.

FIG. **12** is a diagram showing an application-executing VM according to Embodiment 1 of the present invention.

FIG. **13** is a virtual machine management table according to Embodiment 1 of the present invention.

FIG. **14** is a parent and child relationship management table according to Embodiment 1 of the present invention.

FIG. **15**A is a policy table according to Embodiment 1 of the present invention.

FIG. **15**B is a policy table according to Embodiment 1 of the present invention.

FIG. **16** is a block diagram showing a universal OS according to Embodiment 1 of the present invention.

FIG. **17**A is a block diagram showing an application load unit according to Embodiment 1 of the present invention.

FIG. **17**B is a block diagram showing an application load unit according to Embodiment 1 of the present invention.

FIG. **18**A is a block diagram showing an application VMOSX according to Embodiment 1 of the present invention.

FIG. **18**B is a block diagram showing an application VMOSY according to Embodiment 1 of the present invention.

FIG. **19**A is a block diagram showing an OS process requesting unit according to Embodiment 1 of the present invention.

FIG. **19**B is a block diagram showing an OS process requesting unit according to Embodiment 1 of the present invention.

FIG. **20** is a flow chart for application VM generation processing according to Embodiment 1 of the present invention.

FIG. **21** is a flow chart for OS process request according to Embodiment 1 of the present invention.

FIG. **22** is a block diagram showing an application-executing VM creating device according to Embodiment 1 of the present invention.

FIG. **23** is a block diagram showing a virtualization software according to Embodiment 2 of the present invention.

FIG. **24** is a block diagram showing a universal OS according to Embodiment 2 of the present invention.

FIG. **25** is a block diagram showing a virtualization software according to Embodiment 3 of the present invention.

FIG. **26** is a block diagram showing a universal OS according to Embodiment 3 of the present invention.

FIG. **27** is a block diagram showing a cellular phone for which an execution environment is separated using conventional virtualization technology.

FIG. **28** is a block diagram showing a conventional virtual machine creating system.

DESCRIPTION OF EMBODIMENTS

The following describes embodiments according to the present invention with reference to the drawings.

Embodiment 1

When a DL application or DL device driver is executed, an information processing device according to Embodiment 1 of

the present invention creates a virtual machine for the DL application or DL device driver. Consequently, even if a program is a malicious application or a malicious device driver, the program is executed on the dedicated virtual machine, and thus the program cannot access information held by other programs. In this manner, the information processing device according to Embodiment 1 of the present invention prevents the malicious application or the malicious device driver from accessing the information held by the other applications.

<Configuration of Application Distribution System **100**>

FIG. **1** is a schematic diagram showing an application distribution system **100** according to Embodiment 1 of the present invention.

The application distribution system **100** shown in FIG. **1** includes a device **110**, an application distribution server **120**, an apparatus for development **130**, and a device **111**.

The device **110** is, for instance, a cellular phone having a network communication function. The device **110** is connected to the application distribution server **120** via a network, and downloads an application from the application distribution server **120**. Moreover, the device **110** which has downloaded the application obtains a new function by installing the application.

The application distribution server **120** is connected to the device **110** and the apparatus for development **130** via the network. The application distribution server **120** manages applications uploaded by the apparatus for development **130**, and performs a process of downloading an application to the device **110**.

The apparatus for development **130** is connected to the application distribution server **120** via the network, and is an apparatus for developing applications which operate on the device **110**. Moreover, the apparatus for development **130** is connected to the device **111** via an interface compliant with the Universal Serial Bus (hereafter referred to as "USB") standards or the like. A developer develops an application using the apparatus for development **130**, and performs a test to determine whether or not the application operates on the device **111** in an expected manner. When the test finds an error in the application, the developer debugs the application using the apparatus for development **130**. Subsequently, uploading the application to the application distribution server **120** allows the device **110** to use the application. It is to be noted that the devices **110** and **111** are devices having the same functions, and only differ in being used by a general user (the device **110**) or the developer (the device **111**).

Moreover, the devices **110** and **111** correspond to the information processing device according to an implementation of the present invention.

<Software Configuration for Devices **110** and **111**>

FIG. **2** is a software configuration diagram for the devices **110** and **111** according to Embodiment 1 of the present invention.

The devices **110** and **111** shown in FIG. **2** include a normal software execution environment (hereafter referred to as "normal environment") **1000** and a secure software execution environment (hereafter referred to as "secure environment") **1100**. Each of the devices **110** and **111** executes a software (in the normal environment **1000** or secure environment **1100**) by switching between the normal environment **1000** and the secure environment **1100**.

The software in the secure environment **1100** includes a secure OS **1101** and a secure boot unit **1102**. Here, the "secure OS" refers to a "secure operating system".

The secure OS **1101** manages the software in the secure environment **1100**.

The secure boot unit **1102** performs secure boot when the devices **110** and **111** are powered on. The secure boot process is described later with reference to a flow chart.

The method disclosed by, for example, PLT 2 can be used as a method of switching between the normal environment **1000** and the secure environment **1100**.

<Software Configuration for Normal Environment **1000**>

FIG. **3** is a software configuration diagram for the normal environment **1000** according to Embodiment 1 of the present invention.

The software in the normal environment **1000** shown in FIG. **3** includes a virtualization software **1001**, and virtual machines **1002**, **1003**, **1004**, and **1005**.

The virtual machine **1002** includes a virtual hardware **1010**, a universal OS **1011**, a download control application **1012**, an application A **1013**, and an application B **1014**. Moreover, the virtual machine **1003** includes a virtual hardware **1020**, an application VMOSX **1021**, and a DL application X **1022**. Furthermore, the virtual machine **1004** includes a virtual hardware **1030**, an application VMOSY **1031**, and a DL application Y **1032**. Moreover, the virtual machine **1005** includes a virtual hardware **1040**, a RTOS **1041**, and a phone call software **1042**. Here, the "universal OS", the "application VMOS", the "DL application", and the "RTOS" are a "universal operating system", an "application VM operating system", a "downloaded application", and a "real-time operating system", respectively. In addition, the "VM" stands for "Virtual Machine".

The virtualization software **1001** functions to: control the virtual machines **1002** to **1005** operating thereon; allocate hardware resources such as a memory and a CPU to the virtual machines **1002** to **1005** and manage the hardware resources; access devices according to requests from the virtual machines **1002** to **1005**; and schedule the virtual machines **1002** to **1005**. The virtualization software **1001** corresponds to a virtual machine managing unit according to an implementation of the present invention.

The virtual machines **1002** to **1005** include the virtual hardwares, OSs, and applications, and are executed by the virtualization software **1001** independently from each other. Moreover, the virtual machines **1002** to **1005** are independent of each other, and there is no data transfer or exchange of instructions directly between the virtual machines. In other words, the data transfer or the exchange of the instructions between the virtual machines is always performed through the virtualization software **1001**.

Each of the virtual hardwares **1010**, **1020**, **1030**, and **1040** virtually provides a hardware function to a corresponding one of the virtual machines. Moreover, each of the virtual hardwares **1010**, **1020**, **1030**, and **1040** includes an IPL (Initial Program Loader) and a BIOS (Basic Input/Output System). It is to be noted that each of the virtual hardwares **1010**, **1020**, **1030**, and **1040** may be integrated into the virtualization software **1001** or the OS of the corresponding one of the virtual machines, depending on the configuration of the virtualization software **1001**.

The universal OS **1011** loads applications (applications A **1013** and B **1014**) into a memory and executes the applications, or deletes (unloads) an application (application A **1013** or B **1014**) from the memory.

Furthermore, the universal OS **1011** requests the virtualization software **1001** to execute DL applications (DL application X **1022** and DL application Y **1032**).

Moreover, the universal OS **1011** provides a network communication function for the download control application **1012** and the applications A **1013** and B **1014**.

The download control application **1012** communicates with the application distribution server **120** connected to the device **110** via the Internet, and downloads and installs applications to the device **110**.

The applications A **1013** and B **1014** have functions such as an address management function, a web browse function, and an e-mail function, and provide these functions for the user.

In Embodiment 1 of the present invention, the DL applications are downloaded from the application distribution server **120** by the download control application **1012** operating on the universal OS **1011**, and stored in the device **110**. Subsequently, when the universal OS **1011** requests the virtualization software **1001** to execute the DL applications, the virtualization software **1001** performs setting so that each of the DL applications operates on one of the virtual machines. Consequently, the DL application is executed on the virtual machine.

It is to be noted that although Embodiment 1 of the present invention describes a case where the DL applications X **1022** and Y **1032** are downloaded from the application distribution server **120** and executed, the present invention is not limited to the case. In addition, the number of the virtual machines is not limited to 4. In other words, when the universal OS **1011** requests the virtualization software **1001** to execute the DL applications, 4 or more virtual machines may be created, or when the RTOS **1041** requests the virtualization software **1001** to execute the DL applications, such virtual machines may be created.

Each of the applications VMOSX **1021** and VMOSY **1031** is an OS operating on a virtual machine which operates a DL application. The application VMOSX **1021** has a function necessary for the DL application X **1022** to operate. The application VMOSY **1031** has a function necessary for the DL application Y **1032** to operate. It is to be noted that details of the applications VMOSX **1021** and VMOSY **1031** are described later.

Each of the DL applications X **1022** and Y **1032** is an application downloaded from the application distribution server **120**. Like the applications A **1013** and B **1014**, the DL applications X **1022** and Y **1032** provide various functions for the user.

The RTOS **1041** is an OS for operating software providing basic functions of the device.

The phone call software **1042** provides a phone call function that is one of basic functions of the devices **110** and **111**.

It is to be noted that although the virtualization software **1001** performs setting so that each DL application operates on one of the virtual machines, the present invention is not limited to this. For instance, the virtualization software **1001** may perform setting so that each of applications (applications A **1013** and B **1014**) not yet downloaded from the application distribution server **120** operates on one of the virtual machines or part of the DL applications operates on the universal OS **1011**.

It is to be noted that the applications VMOSX **1021** and VMOSY **1031** may have different functions or the same functions. In addition, the applications VMOSX **1021** and VMOSY **1031** may have the same functions as the universal OS **1011**.

<Hardware Configuration for Devices **110** and **111**>

FIG. **4** is a hardware configuration diagram for each of the devices **110** and **111** according to Embodiment 1 of the present invention.

The elements in FIGS. **2** and **3** correspond to elements stored in an internal secure memory **1204** and a memory **1220** shown in FIG. **4**. Each of functions is implemented by executing, on a CPU **1201**, software for implementing each of the elements.

Each of the devices **110** and **111** shown in FIG. **4** includes a system LSI **1200**, a nonvolatile memory device **1240**, and the memory **1220**. The system LSI **1200** is connected to the nonvolatile memory device **1240** and the memory **1220** via external buses.

The system LSI **1200** includes the CPU **1201**, an IPL **1202**, an execution environment switching unit **1203**, and the internal secure memory **1204**. It is to be noted that details of the system LSI **1200** are described later.

The memory **1220** stores the virtualization software **1001**, the universal OS **1011**, the download control application **1012**, the applications A **1013** and B **1014**, the application VMOSX **1021**, the DL application X **1022**, the application VMOSY **1031**, the DL application Y **1032**, the RTOS **1041**, and the phone call software **1042**. This shows a situation where each element shown in FIG. **3** is loaded into the memory **1220**.

The nonvolatile memory device **1240** stores the application-executing VM **1241** and the DL applications X **1242** and Y **1243**.

Although not shown, the nonvolatile memory device **1240** stores softwares to be stored in the memory **1220** and the internal secure memory **1204**. Furthermore, the nonvolatile memory device **1240** may store applications other than the applications A **1013** and B **1014** and the DL applications X **1242** and Y **1243**.

The softwares which are encrypted with predetermined keys and are to be stored in the internal secure memory **1204** are stored in the nonvolatile memory device **1240**. The softwares are stored in the nonvolatile memory device **1240** at the time of factory manufacturing of the devices **110** or **111**. Moreover, the softwares are deployed from the nonvolatile memory device **1240** to the memory **1220** and the internal secure memory **1204** at the time of system start-up or at the time of request for application start-up.

It is to be noted that the keys for encrypting the softwares to be stored in the internal secure memory **1204** may be the same for all the devices or may differ for the respective system LSIs **1200** or the softwares. Moreover, keys for decrypting the encrypted softwares may be stored in a key storage unit (not shown) in the system LSI **1200**, or the softwares which are encrypted with keys stored in the system LSI **1200** may be stored in the nonvolatile memory device **1240**.

Although each of the devices **110** and **111** further includes, for example, an input and output unit not shown in FIG. **4**, a description of the input and output unit and so on is omitted as they do not constitute the essence of the present invention. In addition, although the system LSI **1200** includes, for example, a peripheral circuit not shown in FIG. **4**, a description of the peripheral circuit and so on is omitted as they do not constitute the essence of the present invention.

<Configuration of System LSI **1200**>

The following describes in detail each of the elements in the system LSI **1200** according to Embodiment 1 of the present invention.

The CPU **1201** controls operations of the entire device **110** or **111** by executing instruction codes in, for example, the softwares stored in the memory **1220** and the internal secure memory **1204**. Moreover, the CPU **1201** has two modes, a privileged mode and a non-privileged mode, as operation modes. The universal OS **1011** operates in the privileged mode, and the download control application **1012** and the applications A **1013** and B **1014** operate in the non-privileged mode.

The IPL **1202** is a software which starts first when the device **110** or **111** is powered on. The IPL **1202** starts the secure OS **1101** deployed in the internal secure memory **1204** and the virtualization software **1001** deployed in the memory **1220**, when the device **110** or **111** is powered on. The IPL **1202** is stored in a mask ROM provided in the system LSI **1200**.

The execution environment switching unit **1203** switches between the normal environment **1000** and the secure environment **1100** of the system LSI **1200**. The execution environment switching unit **1203** performs access control so that the internal secure memory **1204** is accessible from the CPU **1201** or the like only when the execution environment of the system LSI **1200** is the secure environment.

The internal secure memory **1204** stores the secure OS **1101** and the secure boot unit **1102**.

It is to be noted that the system LSI **1200** may further include a nonvolatile secure memory (not shown). The execution environment switching unit **1203** performs access control on the nonvolatile secure memory so that the nonvolatile secure memory is accessible from the CPU **1201** or the like only when the execution environment of the system LSI **1200** is the secure environment. It is to be noted that the nonvolatile secure memory may store the softwares to be stored in the internal secure memory **1204** or the keys for decrypting the encrypted softwares.

<Configuration of Application Distribution Server **120**>

FIG. **5** is a schematic diagram showing the application distribution server **120** according to Embodiment 1 of the present invention.

The application distribution server **120** shown in FIG. **5** includes an application holding unit **2000**, an application reception processing unit **2001**, and an application transmission processing unit **2002**.

The application holding unit **2000** holds applications managed by the application distribution server **120**.

The application reception processing unit **2001** communicates with the apparatus for development **130** connected via the network, to receive applications uploaded by the apparatus for development **130**. Moreover, the application reception processing unit **2001** transmits the received applications to the application holding unit **2000**, and requests the application holding unit **2000** to hold and manage the transmitted applications.

The application transmission processing unit **2002** communicates with the device **110** connected via the network. The application transmission processing unit **2002** obtains, from the application holding unit **2000**, applications requested by the device **110**, and transmits the requested applications to the device **110**. Moreover, the application transmission processing unit **2002** creates a list of applications held in the application holding unit **2000**, and transmits the created list to the device **110**.

<Configuration of Apparatus for Development **130**>

FIG. **6** is a block diagram showing the apparatus for development **130** according to Embodiment 1 of the present invention.

The apparatus for development **130** shown in FIG. **6** includes a package generating unit **3000**, a configuration file creating unit **3001**, a key pair holding unit **3002**, a key pair generating unit **3003**, a debug processing unit **3004**, and an upload processing unit **3005**.

The package generating unit **3000** creates an application by compiling source codes developed by a developer. Then, the package generating unit **3000** generates a package file in which an application signature (Signature), a configuration file, and a public key certificate (Certificate) are added to the created application. As an example, a signature scheme using the RSA method can be used for the application signature scheme. It is to be noted that details of the above are described later.

It is to be noted that the application signature (digital signature) scheme is not limited to the RSA method, and other signature schemes may be used. For instance, NPL 2 describes, on pages 171 to 188, the other signature schemes in detail. Moreover, NPL 3 describes the public key certificate in detail.

The configuration file creating unit **3001** creates the configuration file to be added to the application. The configuration file includes various information items such as information indicating which resource of a device the application is to use, information about the developer of the application, and information indicating what kind of service the application provides for other applications. The configuration file creating unit **3001** creates the information items based on values set by the application developer.

The key pair holding unit **3002** holds keys (a key pair of a private key and a public key in a public-key cryptosystem) for use in generating and verifying the application signature to be added to the package. For example, the key pair holding unit **3002** holds the public key in a format of the public key certificate described in NPL 3 (ITU-T Recommendation X. 509).

The key pair generating unit **3003** generates the key pair of the private key and the public key in the public-key cryptosystem, and holds the generated key pair in the key pair holding unit **3002**.

It is to be noted that NPL 2 describes in detail the public-key cryptosystem on pages 107 to 130.

The debug processing unit **3004** communicates with the device **111** connected to the apparatus for development **130** through a USB or the like, and performs a process of debugging an application developed by the developer. Examples of the process of debugging include a process of installing an application by using a generated package, a process of executing an installed application, a process of setting a breakpoint, and a process of obtaining a log output.

The upload processing unit **3005** communicates with the application distribution server **120** connected to the apparatus for development **130** via the network, and performs a process of uploading, to the application distribution server **120**, the package generated by the package generating unit **3000**.

<Configuration of Package Generating Unit **3000**>

FIG. **7** is a block diagram showing the package generating unit **3000** according to Embodiment 1 of the present invention.

The package generating unit **3000** shown in FIG. **7** includes a compiler **3100**, a linker **3101**, and a package generation tool **3102**.

The compiler **3100** creates an object file by compiling inputted source codes **3110**.

The linker **3101** creates a file (executable file) that can be executed by the devices **110** and **111**, by linking the object file created by the compiler **3100** and a library.

The package generation tool **3102** generates a download package **3120** using the executable file created by the linker **3101**, a configuration file **3132** created by the configuration file creating unit **3001**, and a private key **3130** and a public key certificate **3131** held in the key pair holding unit **3002**.

<Structure of Download Package **3120**>

FIG. **8** is a diagram showing the download package **3120** according to Embodiment 1 of the present invention.

In FIG. **8**, the download package **3120** includes an application **3200**, a device driver **3201**, a configuration file **3202**, an application signature list **3203**, and a public key certificate **3204**.

The application **3200** and the device driver **3201** are executable files created by the compiler **3100** and the linker **3101** from the source codes **3110** developed by the developer.

The configuration file **3202** is the same as the configuration file **3132** inputted to the package generation tool **3102**.

The application signature list **3203** is a list including signatures of the application **3200**, the device driver **3201**, and the configuration file **3202**. The package generation tool **3102** generates the signatures from the application **3200**, the device driver **3201**, and the configuration file **3202** that are inputted at the time of generating the download package **3120**, and creates the application signature list **3203**. The private key **3130** is used by the application signature list **3203** to generate the signatures.

The public key certificate **3204** is the same as the public key certificate **3131** inputted to the package generation tool **3102**.

It is to be noted that although the download package **3120** includes, as a file, each of the application **3200**, the device driver **3201**, the configuration file **3202**, the application signature list **3203**, and the public key certificate **3204**, the present invention is not limited to this. For instance, each of the files may be one or plural in number. Moreover, part of the files may be included in the download package **3120**. Furthermore, the files may be downloaded in one file as the download package **3120**, may be separately downloaded, or may be downloaded after being divided into files.

It is to be noted that the application signature list **3203** may include a signature for the entire list including the signatures of the application **3200**, the device driver **3201**, and the configuration file **3202**. Moreover, the download package **3120** may include the signatures of the application signature list **3203**.

<Secure Boot Process>

The devices **110** and **111** verify, at the time of their start-up, whether or not the virtualization software **1001** and a software operating in the secure environment **1100** have been tampered with.

The following describes a method (secure boot process) from when the devices **110** and **111** are powered on to when the virtualization software **1001** starts, with reference to a flow chart shown in FIG. **9**.

When powered on, the device **110** or **111** starts the IPL **1202** in the system LSI **1200**.

The IPL **1202** first performs an initialization process on hardware of the device **110** or **111** (S**1000**). In the initialization, process, the following processes are performed: operation check on the memory **1220**, initialization of the execution environment switching unit **1203**, initialization of the peripheral circuit (not shown), and so on. Subsequently, the secure OS **1101** is started.

The secure OS **1101** performs initialization of the secure environment **1100** (implementation of a secure software execution environment), thereby allowing an application to operate in the secure environment **1100**. Subsequently, the secure OS **1101** loads the secure boot unit **1102** (S**1001**), and starts the secure boot unit **1102**.

Here, the secure boot unit **1102** is stored in encrypted state in the nonvolatile memory device **1240**. Thus, the execution environment switching unit **1203** decrypts the encrypted secure boot unit **1102** using a key unique to the system LSI **1200**, and loads the decrypted secure boot unit **1102** to the internal secure memory **1204**.

The secure boot unit **1102** verifies the secure OS **1101** and the secure boot unit **1102** (S**1002**). As a verification method, the secure boot unit **1102** verifies whether or not the secure OS **1101** and the secure boot unit **1102** have been tampered with, by generating a hash value of a software and comparing the generated hash value with a pre-calculated reference hash value. Here, the reference hash value is calculated before factory shipment, and is embedded in the secure boot unit **1102**. Moreover, the secure boot unit **1102** is encrypted with the reference hash value embedded, and stored in the nonvolatile memory device **1240**.

It is to be noted that although the hash value is used in the verification method for software here, the present invention is not limited to this. A method in which a signature is used instead of the hash value may be employed. Here, the secure boot unit **1102** may be encrypted with a public key for use in signature verification embedded, and stored in the nonvolatile memory device **1240**. The public key may be stored in the nonvolatile memory device **1240** separately from the secure boot unit **1102**. Moreover, the secure boot unit **1102** may obtain the public key from another apparatus outside the device.

When the secure boot unit **1102** determines that the secure OS **1101** and the secure boot unit **1102** have not been tampered with, based on a result of the verification of the secure OS **1101** and the secure boot unit **1102** in step S**1002**, the secure boot unit **1102** determines YES in step S**1003**, and the flow proceeds to step S**1004**. Moreover, when the secure boot unit **1102** determines that one of the secure OS **1101** and the secure boot unit **1102** has been tampered with, based on the result of the verification of the secure OS **1101** and the secure boot unit **1102** in step S**1002**, the secure boot unit **1102** determines NO in step S**1003**, and the flow proceeds to step S**1006**.

When the secure boot unit **1102** determines YES in step S**1003**, the secure boot unit **1102** verifies the virtualization software **1001** (S**1004**). For instance, the secure boot unit **1102** employs the same verification method as in step S**1002**.

When the secure boot unit **1102** determines that the virtualization software **1001** has not been tampered with, based on a result of the verification of the virtualization software **1001** in step S**1004**, the secure boot unit **1102** determines YES in step S**1005**, ends the process, and returns the process to the secure OS **1101**. In contrast, when the secure boot unit **1102** determines that the virtualization software **1001** has been tampered with, based on the result of the verification in step S**1004**, the secure boot unit **1102** determines NO in step S**1005**, and the flow transits to step S**1006**.

When the secure boot unit **1102** determines NO in either step S**1003** or step S**1005**, the secure boot unit **1102** sets a secure boot failure flag (S**1006**). The secure boot failure flag is data stored in a specific area of the internal secure memory **1204** (not shown). The secure OS **1101** and an application which operates on the secure OS **1101** recognize a state of the device **110** or **111** by checking the secure boot failure flag, and determine whether to operate or not.

After the end of the process in step S**1006**, the secure boot unit **1102** returns the process to the secure OS **1101**.

When the process is returned from the secure boot unit **1102**, the secure OS **1101** returns the process to the IPL **1202**.

The IPL **1202** loads, to the memory **1220**, the virtualization software **1001** stored in the nonvolatile memory device **1240** (S**1007**), and executes (starts) the virtualization software **1001**.

It is to be noted that secure boot which is defined by the MPWG (Mobile Phone Work Group) of the TCG (Trusted Computing Group) may be employed in the secure boot process.

Moreover, here, although the verification of the secure mode software (S**1002**) is followed by the verification of the virtualization software (S**1004**), the present invention is not limited to this. For example, after the secure boot unit **1102** performs the verification of the secure mode software (S**1002**), the secure boot unit **1102** may temporarily return the process to the IPL **1202**, and the IPL **1202** may successively request, via the secure OS **1101**, the verification of the virtualization software (S**1004**) from the secure boot unit **1102**.

Furthermore, although the secure boot process ends when the virtualization software **1001** is executed, the present invention is not limited to this. A scope of the secure boot process may include an IPL, an OS, and an application in a virtual machine. In the case where the scope of the secure boot process includes the IPL, the OS, and the application, each of the IPL, the OS, and the application verifies whether or not a software to be started next has been tampered with, and then starts (executes) the software to be started next.

<Start Process of Virtual Machine>

The virtualization software **1001** starts a predetermined virtual machine at the time of device startup. In addition, the virtualization software **1001** newly creates a virtual machine in response to a request from a running virtual machine.

The following describes a process in which each of virtual machines starts after a start of the virtualization software **1001** with reference to a flow chart shown in FIG. **10**.

The virtualization software **1001** is started by the IPL **1202** at the end of the secure boot process, and performs an initialization process (S**1010**). After the initialization process, the virtualization software **1001** reserves hardware resources such as a memory for executing the virtual machine **1002**, and then starts the virtual machine **1002**.

When started, the virtual machine **1002** first performs an initialization process (S**1011**). The virtual machine **1002** executes the IPL **1202** in the virtual hardware **1010** as the initialization process. Moreover, the virtual machine **1002** loads the universal OS **1011** to the memory, and executes the universal OS **1011**. Subsequently, during or after a start process of the universal OS **1011**, a process request from the virtual machine **1002** to the virtualization software **1001** or hardware interrupt aborts a process of the virtual machine **1002**, and the process is returned to the virtualization software **1001**.

Next, the virtualization software **1001** reserves hardware resources such as a memory for executing the virtual machine **1005**, and starts the virtual machine **1005**.

When started, the virtual machine **1005** first performs an initialization process (S**1012**). The virtual machine **1005** executes the IPL **1202** in the virtual hardware **1040** as the initialization process. Moreover, the virtual machine **1005** loads the RTOS **1041** to the memory, and executes the RTOS **1041**. Subsequently, during or after a start process of the RTOS **1041**, a process request from the virtual machine **1005** to the virtualization software **1001** or hardware interrupt aborts a process of the virtual machine **1005**, and the process is returned to the virtualization software **1001**.

Then, the virtualization software **1001** schedules each virtual machine according to a scheduling function.

When the virtual machine **1002** is executed according to the scheduling function, the virtual machine **1002** starts the application based on a request from the user using the device (S**1013**).

At the time of starting the application, the virtual machine **1002** determines whether the application of which start has been requested is to be operated by the virtual machine **1002** or another virtual machine. Specifically, the virtual machine **1002** determines whether or not the application of which start has been requested is a DL application (S**1014**). It is to be noted that the DL application is not limited to an application downloaded from another apparatus via the network, and may be an application obtained from still another apparatus. For instance, the DL application may be an application which the device **110** obtains via a recording medium detachable to the device **110** after shipment. Alternatively, the virtual machine **1002** may determine whether or not the application of which start has been requested is a DL device driver.

When the application is the DL application, the virtual machine **1002** determines "YES", and when the application is not the DL application, the virtual machine **1002** determines "NO". For example, the virtual machine **1002** uses an extension assigned to a file name of the application of which start has been requested, for the determination of the DL application.

When the virtual machine **1002** determines "YES" in step S**1014**, the virtual machine **1002** requests the virtualization software **1001** to create a VM (application VM) for executing the application of which start has been requested.

The virtualization software **1001** creates the virtual machine **1003** for executing DL application (S**1015**), and starts the virtual machine **1003**. Details of the VM creation process are described later with reference to a flow chart.

When started, the virtual machine **1003** performs an initialization process (S**1017**), and executes the application of which start has been requested (S**1018**). Moreover, during the execution of the DL application (S**1018**), a process request from the virtual machine **1003** to the virtualization software **1001** or hardware interrupt may abort a process of the virtual machine **1003**, and the process may be returned to the virtualization software **1001**. In this case, when the virtual machine **1003** is rescheduled, the virtual machine **1003** executes the aborted process according to the scheduling function of the virtualization software **1001**. When the application ends, the virtual machine **1003** sends notice of an end of the virtual machine to the virtualization software **1001**.

Upon receiving the notice of the end from the virtual machine **1003**, the virtualization software **1001** sends notice of the end of the VM to the virtual machine **1002**.

Upon receiving the notice of the end of the VM, the virtual machine **1002** recognizes that the application of which start was requested in step S**1013** has ended.

On the other hand, when the virtual machine **1002** determines "NO" in step S**1014**, the virtual machine **1002** executes the application of which start has been requested (S**1016**).

As stated above, each of the devices **110** and **111** according to Embodiment 1 of the present invention starts the predetermined virtual machine at the time of the start of a corresponding one of the devices **110** and **111**. Furthermore, when the user requests the started predetermined virtual machine to start the DL application, each of the devices **110** and **111** additionally starts a virtual machine for DL application (virtual machine **1003**), and executes the DL application in the virtual machine.

It is to be noted that when the virtual machine **1002** requests creation of another VM for executing DL application, during the abortion of the process of the virtual machine **1003**, the virtualization software **1001** creates a virtual machine (e.g. virtual machine **1004**) other than the virtual machine **1003**, and allows the DL applications to be operated on the different virtual machines, respectively.

<Configuration of Virtualization Software **1001**>

FIG. **11** is a software configuration diagram showing the virtualization software **1001** according to Embodiment 1 of the present invention.

In FIG. **11**, the virtualization software **1001** includes an application VM creating unit **1300**, an application-executing VM obtaining unit **1301**, a VM managing unit **1302**, an OS process request control unit **1303**, a parent and child relationship managing unit **1304**, and a policy managing unit **1305**.

Upon receiving a request to create a virtual machine (application VM) from a virtual machine operating on the virtualization software **1001**, the application VM creating unit **1300** creates a virtual machine (application VM) for executing DL application. Here, the application VM creating unit **1300** creates the virtual machine (application VM) according to an application-executing VM and a DL application transmitted from a virtual machine. Moreover, the application VM creating unit **1300** requests the VM managing unit **1302** to manage the created virtual machine. Furthermore, the application VM creating unit **1300** registers, in the parent and child, relationship managing unit **1304**, the virtual machine which has requested the creation of the virtual machine as a "parent", and the created virtual machine as a "child". It is to be noted that details of the VM creation process are described later with reference to a flow chart.

Moreover, here, although the application VM creating unit **1300** creates the virtual machine for executing DL application, based on the application-executing VM and the DL application transmitted from the virtual machine, the present invention is not limited to this. For example, the application VM creating unit **1300** may download, from the application distribution server **120**, a virtual machine including an application, an OS, and a virtual hardware, perform a process of loading the virtual machine, and request management from the VM managing unit **1302**. Moreover, the application VM creating unit **1300** may create the virtual machine not at the time of executing the DL application but at the time of downloading the DL application from the application distribution server **120**.

The application-executing VM obtaining unit **1301** reads the application-executing VM **1241** stored in the nonvolatile memory device **1240**.

FIG. **12** is a diagram showing the structure of the application-executing VM **1241** according to Embodiment 1 of the present invention. The application-executing VM **1241** includes header information **1310**, a VM main portion **1311**, and a verification value **1312**. The VM main portion **1311** includes an OS **1315** and a virtual hardware **1316**. The header information **1310** includes an address (logical address) for writing an application to be executed, and an address (logical address) of a management structure which manages device drivers. The verification value **1312** is a hash value that is obtained when the VM main portion **1311** is inputted into a hash function. The OS **1315** corresponds to an OS for VM according to an implementation of the present invention, and the nonvolatile memory device **1240** corresponds to a storage unit according to an implementation of the present invention.

It is to be noted that the verification value **1312** may be not behind of the VM main portion **1311** but ahead of the VM main portion **1311**, or may be included in the header information **1310**. Furthermore, the verification value **1312** may be not included in the application-executing VM **1241** but stored, in association with the application-executing VM **1241**, in the nonvolatile secure memory separately from the application-executing VM **1241**.

It is to be noted that an algorithm such as MD4, MD5, SHA-1 (Secure Hash Algorithm-1), and SHA-2 can be used as the hash function. Moreover, the verification value **1312** may be not the hash value but a digital signature, a MAC (Message Authentication Code) value, an error-detecting code value, or an error-correcting code value. For example, CBC-MAC (Cipher Block Chaining Message Authentication Code) and HMAC (Keyed-Hashing for Message Authentication Code) can be used as an algorithm for calculating the MAC value. Moreover, for example, CRC (Cyclic Redundancy Check) and a checksum can be used as an algorithm for calculating the error-detecting code value. Furthermore, for example, Reed-Solomon codes and Turbo codes can be used as an algorithm for calculating the error-correcting code value.

It is to be noted that NPL 4 describes in detail hash functions on pages 96 to 105, and Message Authentication Code on pages 30 to 39, and that NPL 2 describes in detail digital signature schemes on pages 171 to 188.

It is to be noted that application-executing VMs **1241** may be stored in the nonvolatile memory device **1240**, and the application-executing VM obtaining unit **1301** may switch between the application-executing VMs **1241** to be used, depending on a DL application. Here, the header information **1310** of each of the application-executing VMs **1241** may include information which indicates functions of the application-executing VM **1241** or information which associates the application-executing VM **1241** with the DL application.

The VM managing unit **1302** manages virtual machines which are operating on the virtualization software **1001**. The VM managing unit **1302** manages a virtual machine which starts at the time of device startup, together with a VM for executing DL application. Moreover, the VM managing unit **1302** uses a virtual machine management table **1350** shown in FIG. **13**, for the management of the virtual machines. The virtual machine management table **1350** includes a virtual machine ID for identifying a virtual machine, a status of a virtual machine, an address range of a memory used by a virtual machine, and a destination for storing a suspension state at the time of suspending a virtual machine.

Upon receiving an OS process request from the virtual machine operating on the virtualization software **1001**, the OS process request control unit **1303** requests a virtual machine that is a "parent" of the requesting virtual machine to execute the OS process. The OS process request control unit **1303** obtains, from the parent and child relationship managing unit **1304**, information about the "parent" virtual machine. It is to be noted that details of the OS request process are described later with reference to a flow chart.

The parent and child relationship managing unit **1304** manages the parent and child relationship between the virtual machines based on notice from the application VM creating unit **1300**. The parent and child relationship managing unit **1304** manages the parent and child relationship using a parent and child relationship management table **1360**. FIG. **14** shows a structure of the parent and child relationship management table **1360**. The parent and child relationship management table **1360** includes an ID of a "parent" virtual machine (parent virtual machine ID) and an ID of a "child" virtual machine (child virtual machine ID). Moreover, each of the parent virtual machine ID and the child virtual machine ID corresponds to one of the IDs in the virtual machine management table **1350**.

The policy managing unit **1305** determines, for each of functions achieved through the OS process request, whether or not it is possible to request another virtual machine to execute the OS process for the function. Specifically, when receiving the OS process request from the virtual machine, the policy managing unit **1305** determines whether or not to

execute the OS process, based on a policy table **1370**. As shown in FIG. **15**A, the policy table **1370** includes functions and virtual machine IDs. All functions of devices are listed in the function column, and virtual machine IDs each corresponding to one of the functions are listed in the virtual machine ID column. Here, regarding a function which cannot be used by a DL application, a special ID indicating use prohibition ("0" in FIG. **15**A) is stored as a virtual machine ID.

It is to be noted that the policy table may be as shown in FIG. **15**B. A policy table **1371** shown in FIG. **15**B includes functions, and symbols each indicating whether or not one of virtual machines is permitted to access one of the functions. "Yes" in FIG. **15**B indicates access granted, and "No" in FIG. **15**B indicates access denied.

Although a policy is determined for each virtual machine here, the present invention is not limited to this. The policy may be determined for each DL application. In this case, information for associating a DL application with a virtual machine is added to the virtual machine management table **1350**.

Although TV viewing, phone call, and play back of commercial content are shown as examples of the functions in FIGS. **15**A and **15**B, the functions are not limited to these. For instance, to determine whether or not to send a process request to a device driver, the policy managing unit **1305** may store, into the policy table **1370** or **1371**, information indicating whether or not use is prohibited for each device driver. Moreover, the policy managing unit **1305** may store, into the policy table **1370** or **1371**, information indicating whether or not use is prohibited for each inner function of an OS such as a memory handling function. Furthermore, the policy managing unit **1305** may store, into the policy table **1370** or **1371**, information obtained by combining the above information items.

Moreover, because an OS process request among OS process requests from a virtual machine is not essentially received for a process to be executed inside an application VMOS, use by a DL application may be prohibited when such a process request is received. Examples of the process to be executed inside the application VMOS include a process of installing a downloaded device driver, a process of executing a downloaded device driver, and a process concerning a function relevant to a memory map. It is to be noted that details of the above are described later.

<Configuration of Universal OS **1011**>

FIG. **16** is a block diagram showing the universal OS **1011** according to Embodiment 1 of the present invention.

In FIG. **16**, the universal OS **1011** includes an application load unit **1400**, an application VM OS process receiving unit **1401**, and a device driver A **1402**.

Upon receiving, from the user, a request to start an application, the application load unit **1400** performs an application start process. The application load unit **1400** determines whether or not the application of which start has been requested by the user is a DL application. When the application of which start has been requested by the user is the DL application, the application load unit **1400** requests the virtualization software **1001** to create an application VM. When the application of which start has been requested by the user is not the DL application but a normal application, the application load unit **1400** executes the application as an application operating on the universal OS **1011**.

Upon receiving the OS process request from the virtualization software **1001**, the application VM OS process receiving unit **1401** executes the requested OS process, and notifies the virtualization software **1001** of the result of the executed OS process. The application VM OS process receiving unit **1401** receives, from the virtualization software **1001**, an identifier and a parameter for the OS process to be executed, and execute the process according to the identifier. Moreover, the application VM OS process receiving unit **1401** registers a callback function for the virtualization software **1001** during the initialization process for the universal OS **1011**, and receives an OS process request using the callback function.

It is to be noted that although the application VM OS process receiving unit **1401** receives the OS process request via the callback function, the present invention is not limited to this. The present invention includes a mechanism which may cause the virtualization software **1001** to send the request to the universal OS **1011**. For example, as a virtual hardware function, the application VM OS process receiving unit **1401** may receive the OS process request through interrupt processing dedicated for OS process request. Moreover, the application VM OS process receiving unit **1401** may add a system call dedicated for OS process request to the system call of the universal OS **1011**, and receive the OS process request via the system call.

The device driver A**1402** manages access to a hardware attached to the device **110** or **111**. The device driver A **1402** operates according to a request from an application which operates in and on the universal OS **1011**.

<Configuration of Application Load Unit **1400**>

FIG. **17**A is a block diagram showing the application load unit **1400** according to Embodiment 1 of the present invention.

The application load unit **1400** shown by FIG. **17** includes an application obtaining unit **1410**, a determining unit **1411**, a load unit **1412**, and a VM creation requesting unit **1413**.

The application obtaining unit **1410** reads, from the non-volatile memory device **1240**, an application of which start has been requested by the user.

The determining unit **1411** determines whether or not the application of which start has been requested by the user is a DL application. When the application of which start has been requested by the user is not the DL application, the determining unit **1411** requests the load unit **1412** to load and start the application. When the application of which start has been requested by the user is the DL application, the determining unit **1411** requests the VM creation requesting unit **1413** to start the DL application.

As a method of determining a DL application, for example, the determining unit **1411** determines whether or not an extension assigned to a file name of the application of which start has been requested matches a predetermined extension by comparing the extensions. An extension (predetermined extension) used by the DL application is determined at the time of system design, embedded in the universal OS **1011** in advance, and used for the comparison.

It is to be noted that although the determining unit **1411** uses the extension for the determination of the DL application, the present invention is not limited to this. For instance, the DL application may be stored in a specific directory (folder), and the determining unit **1411** may determine whether or not a name of a directory (name of a folder) of the application of which start has been requested matches a name of the directory in which the DL application is stored, by comparing the names. Moreover, information (identifier) for indicating a DL application may be embedded in header information of the DL application, and the determining unit **1411** may check whether or not the information exists. Furthermore, the determining unit **1411** may determine whether the application is the DL application by using information in the public key certificate **3204** in the download package **3120**

of the DL application. Examples of such a determining method include a method of determining whether or not information for identifying a subject or issuer is information indicating a specific enterprise, and a method of checking whether a certificate serial number is composed of a specific character string. Moreover, a DL application managing unit which manages DL applications downloaded from the application distribution server **120** may be provided, and the determining unit **1411** may determine whether the application of which start has been requested is the DL application depending on whether or not the application is an application managed by the DL application managing unit.

The load unit **1412** writes, into the memory **1220**, the application read by the application obtaining unit **1410**, performs processes necessary for starting the application (e.g. analysis of header, setting of logical address, setting of stack, and setting of entry point), and then executes the application.

Upon receiving the request to start the DL application from the determining unit **1411**, the VM creation requesting unit **1413** requests the virtualization software **1001** to create an application VM. Moreover, at the time of the request, the VM creation requesting unit **1413** transmits, to the virtualization software **1001**, the DL application to be executed on the application VM.

It is to be noted that as shown by FIG. **17**B, the application load unit **1400** may include only the determining unit **1411**, the load unit **1412**, and the VM creation requesting unit **1413**. In this case, the functions of the application obtaining unit **1410** may be included in the determining unit **1411**, or may be included in the application VM creating unit **1300** and the load unit **1412** of the virtualization software **1001**.

<Configurations of Application VMOSX **1021** and Application VMOSY **1031**>

Each of FIGS. **18**A and **18**B is a block diagram showing an application VMOS according to Embodiment 1 of the present invention. FIG. **18**A is the block diagram showing the configuration of the application VMOSX **1021**, and FIG. **18**B is the block diagram showing the configuration of the application VMOSY **1031**.

The application VMOSX **1021** shown by FIG. **18**A includes an OS process requesting unit **1500** and a device driver B **1501**.

Upon receiving an OS process request from the DL application X **1022** operating on the application VMOSX **1021**, the OS process requesting unit **1500** requests the virtualization software **1001** to execute the OS process. Here, when the OS process request is a process request for the device driver B **1501**, the process request is sent not to the virtualization software **1001** but directly to the device driver B **1501** from within the application VMOSX **1021**.

The device driver B **1501** is a device driver operating within the application VMOSX **1021**, and is used not by other applications but by only the DL application X **1022**.

The application VMOSY **1031** shown by FIG. **18**B includes the OS process requesting unit **1500**.

It is to be noted that although the device driver B **1501** is used not by the other applications but by only the DL application X **1022**, the present invention is not limited to this. For instance, the DL application Y **1032** may use the device driver B **1501**. In this case, the application VMOSY **1031** further includes the device driver B **1501**. The DL application Y **1032** uses the device driver B **1501** included in the application VMOSY **1031**.

Upon receiving an OS process request from the DL application X **1032** operating on the application VMOSX **1031**, the OS process requesting unit **1500** requests the virtualization software **1001** to execute the OS process. Since the application VMOSY **1031** has no device driver inside, the OS process requesting unit **1500** requests the virtualization software **1001** to execute all OS process.

<Configuration of OS Process Requesting Unit **1500**>

FIG. **19**A is a block diagram showing the OS process requesting unit **1500** according to Embodiment 1 of the present invention.

The OS process requesting unit **1500** shown by FIG. **19**A includes an OS process receiving unit **1510**, a request determining unit **1511**, an internal processing unit **1512**, and a requesting unit **1513**.

The OS process receiving unit **1510** receives an OS process request from a DL application.

The request determining unit **1511** determines whether the requested OS process is a process to be executed within an application VMOS or a process to be requested to the virtualization software **1001**. When determining that the requested OS process is the process to be executed internally, the request determining unit **1511** requests the internal processing unit **1512** to execute the process. Moreover, when determining that the requested OS process is the process to be requested to the virtualization software **1001**, the request determining unit **1511** requests the requesting unit **1513** to execute the process.

The internal processing unit **1512** calls the process requested by the DL application, and feeds back the processing result to the DL application.

The requesting unit **1513** requests the virtualization software **1001** to execute the OS process. Moreover, the requesting unit **1513** feeds back, to the DL application, a result obtained from the virtualization software **1001**.

Examples of a process determined by the request determining unit **1511** as the process to be executed inside the application VMOS include the process of installing a downloaded device driver, the process of executing a downloaded device driver, and the process concerning a function relevant to a memory map.

It is to be noted that the OS process requesting unit **1500** determines whether or not the OS process request is the process to be executed internally, the present invention is not limited to this. Like the OS process requesting unit **1500** shown by FIG. **19**B, the virtualization software **1001** may be requested to execute all processes without determining whether or not each requested OS process is the process to be executed internally.

<Application VM Creation Process>

The universal OS **1011** and the virtualization software **1001** perform an application VM creation process so that the universal OS **1011** and the virtualization software **1001** cause a DL application to operate on an application VMOS in cooperation with each other.

The following describes an application VM creation process at the time when the universal OS **1011** requests the virtualization software **1001** to create an application VM, with reference to a flow chart shown in FIG. **20**.

In response to an application execution request from the user, the universal OS **1011** performs an application start process. First, the application load unit **1400** of the universal OS **1011** obtains the application of which execution has been requested, from the nonvolatile memory device **1240** (S**1100**), and writes the obtained application into the memory **1220**.

The application load unit **1400** determines whether or not the obtained application is a DL application (S**1101**). When the obtained application is the DL application, the application

load unit **1400** determines "YES", and when the obtained application is not the DL application, the application load unit **1400** determines "NO".

When the application load unit **1400** determines "YES" in step S**1101**, the application load unit **1400** requests the virtualization software **1001** to create a VM (application VM) for executing the application of which execution has been requested. Here, the application load unit **1400** sends, to the virtualization software **1001**, the obtained application together with the request.

Upon receiving the application VM creation request, the application VM creating unit **1300** of the virtualization software **1001** reserves, on the memory **1220**, a memory area for an application VM to be created, reads the application-executing VM **1241** from the nonvolatile memory device **1240**, and writes the VM main portion **1311** into the reserved memory area (S**1102**). Subsequently, the application VM creating unit **1300** generates a verification value from the written VM main portion **1311** so as to verify whether the correct VM main portion **1311** is written. Next, the application VM creating unit **1300** compares the generated verification value with the verification value **1312** of the application-executing VM **1241**, and verifies whether or not the verification values match each other. When the generated verification value does not match the verification value **1312** of the application-executing VM **1241**, the application VM creating unit **1300** stops creating the application VM.

It is to be noted that although the application VM creating unit **1300** verifies the verification value **1312** after writing the VM main portion **1311** into the memory **1220**, the present invention is not limited to this. For instance, the application VM creating unit **1300** may calculate a verification value of the VM main portion **1311** before reading the application-executing VM **1241** from the nonvolatile memory device **1240**, and verify whether or not the calculated verification value matches the verification value **1312**.

Moreover, when the application VM creating unit **1300** creates virtual machines for respective DL applications, the application VM creating unit **1300** uses the OS **1315** in common. For example, the application VM creating unit **1300** creates, using the OS **1315**, both the application VMOSX **1021** of the virtual machine **1003** which executes the DL application X **1022** and the application VMOSY **1031** of the virtual machine **1004** which executes the DL application Y **1032**. Specifically, when both the DL application X **1022** and the DL application Y **1032** do not include the DL device driver, the application VMOSX **1021** and the application VMOSY **1031** have the same function. Moreover, when the DL application X **1022** includes the DL device driver, the application VM creating unit **1300** creates the application VMOSX **1021** by adding a function of the DL device driver to the OS **1315**.

Here, as stated above, the device **110** according to Embodiment 1 of the present invention creates the virtual machines for the respective DL applications, and causes the virtual machines to execute the DL applications. Consequently, an OS is required for each application, which leads to a problem that a capacity of the nonvolatile memory device **1240** for storing the OSs needs to be increased. In response, the application VM creating unit **1300** creates the OS for each application, using the common OS **1315**. This makes it only necessary to store only the single OS **1315** in the nonvolatile memory device **1240**, and thus it is possible to reduce the capacity of the nonvolatile memory device **1240**.

Next, the application VM creating unit **1300** writes, into the memory **1220**, the application received from the universal OS **1011** (S**1103**). Moreover, the application VM creating unit **1300** refers to, as a write address, an address described in the header information **1310** of the application-executing VM **1241**. Furthermore, the application VM creating unit **1300** registers, in the VM managing unit **1302**, the application VM created from the application-executing VM **1241** and the application, and assigns, to the created application VM, an ID for identifying the application VM (virtual machine).

Next, the application VM creating unit **1300** obtains an ID (ID **1**) of a virtual machine which executes the universal OS **1011** requesting the VM creation process, and an ID (ID **2**) of the created application VM. Moreover, the application VM creating unit **1300** stores, into the parent and child relationship managing unit **1304**, a parent and child relationship in which the ID **1** refers to a "parent" and the ID **2** refers to a "child" (S**1104**).

Next, the application VM creating unit **1300** requests the VM managing unit **1302** to execute the created application VM. This enables the VM managing unit **1302** to execute the application VM (S**1105**). In the executed application VM, the application VMOS is executed, and further the DL application is executed.

On the other hand, when the application load unit **1400** determines "NO" in step S**1101**, the application load unit **1400** registers, in the universal OS **1011**, the obtained application as an application which operates on the universal OS **1011**, and executes the application (S**1106**).

<Processing at Time of OS Process Request>

When the application VMOSX **1021** or the application VMOSY **1031** receives an OS process request from a corresponding one of the DL applications X **1022** and Y **1032** which operate on the respective applications VMOSX **1021** and VMOSY **1031**, the application VMOSX **1021** or the application VMOSY **1031** requests the virtualization software **1001** to execute the OS process. Upon receiving the OS process request, the virtualization software **1001** requests the universal OS **1011** which is capable of executing the OS process to execute the OS process.

The following describes processing of an OS process request from an DL application with reference to a flow chart shown by FIG. **21**. Hereinafter, a case is described where the universal OS **1011** handles an OS process request from the DL application X **1022** operating on the application VMOSX **1021**. Here, it is assumed that the virtual machine ID of the virtual machine **1002** operated by the universal OS **1011** is "1", and that the virtual machine ID of the virtual machine **1003** operated by the application VMOSX **1021** and the DL application X **1022** is "3". It is also assumed that a set of the parent virtual machine ID "1" and the child virtual machine ID "3" is registered in the parent and child relationship management **1360** as shown by FIG. **14**.

In FIG. **21**, the DL application X **1022** issues a system call such as access to a device, to request the application VMOSX **1021** to execute an OS process. The requested application VMOSX **1021** determines whether the requested OS process is a process to be executed inside the application VMOSX **1021** or a process of requesting another virtual machine (S**1200**). The application VMOSX **1021** determines "YES" when it is determined that the requested OS process is the process to be executed inside the application VMOSX **1021**, and "NO" when it is determined otherwise.

Specifically, the application VMOSX **1021** determines whether or not the application VMOSX **1021** successfully executes the requested OS process. For instance, when the application VMOSX **1021** includes functions of a DL device driver and the requested OS process is a process of the DL device driver, the application VMOSX **1021** determines that the application VMOSX **1021** successfully executes the OS

process (the OS process is the process to be executed inside the application VMOSX **1021**). Moreover, when the requested OS process is other than the process of the DL device driver, the application VMOSX **1021** determines that the application VMOSX **1021** fails to execute the OS process (the OS process is the process of requesting the other virtual machine).

When determining "NO" in step S**1200**, the application VMOSX **1021** requests the virtualization software **1001** to execute the OS process. The OS process request control unit **1303** of the virtualization software **1001** checks with the parent and child relationship managing unit **1304** so as to determine which virtual machine is a virtual machine that is a "parent" of the virtual machine having requested the OS process, and obtains the identifier of the "parent" virtual machine (S**1201**). The checked parent and child relationship managing unit **1304** searches the child virtual machine ID column of the parent and child relationship management **1360** for the ID (in this case "3") of the virtual machine having requested the OS process. Then, the parent and child relationship managing unit **1304** obtains a parent virtual machine ID (in this case "1") that is managed with the searched ID as a set, and notifies the OS process request control unit **1303** of the obtained parent virtual machine ID.

Next, the OS process request control unit **1303** requests the policy managing unit **1305** to check whether the requested OS process complies with a policy. The requested policy managing unit **1305** checks the compliance with the policy with reference to the policy table **1370** (S**1202**). Moreover, the policy managing unit **1305** obtains, from the policy table **1370**, a virtual machine ID of a virtual machine providing the function, and checks whether the virtual machine ID is a special ID indicating use prohibition (in the case shown by FIG. **15**A, "0"). When the virtual machine ID is the special ID, the policy managing unit **1305** feeds back "NO" as the check result. Moreover, when the virtual machine ID is not the special ID, the policy managing unit **1305** feeds back "YES" as the check result.

The OS process request control unit **1303** determines whether the check result in step S**1202** indicates "YES" (S**1203**).

When determining "YES" in step S**1203**, the OS process request control unit **1303** requests the universal OS **1011** operating on the virtual machine **1002** that is the "parent" to execute the OS process.

The universal OS **1011** executes the requested OS process (S**1204**), and notifies the universal OS **1001** of the result of the executed OS process. The virtualization software **1001** notifies the application VMOSX **1021** of the notified result. The application VMOSX **1021** further notifies the DL application X **1022** of the notified result.

In contrast, when determining "NO" in step S**1203**, the OS process request control unit **1303** notifies the application VMOSX **1021** of an error as the result.

Moreover, when determining "YES" in step S**1200**, the application VMOSX **1021** executes the OS process internally (S**1205**). Then, the application VMOSX **1021** notifies the DL application X **1022** of the result of the executed OS process.

It is to be noted that although the case is described where the DL application X **1022** requests the OS process and the universal OS **1011** executes the OS process, the present invention is not limited to the case. For example, an application operating on another application VM may request the OS process, and an OS other than the universal OS **1011** may execute the OS process.

Here, as stated above, the device **110** according to Embodiment 1 of the present invention creates the virtual machines for the respective DL applications, and causes the virtual machines to execute the DL applications. Consequently, an OS is required for each virtual machine, which leads to a problem that a capacity of necessary hardware (e.g. a memory) needs to be increased. In response, in the device **110** according to Embodiment 1 of the present invention, the virtual machine created for the DL application requests another virtual machine to execute the OS process which the OS of the virtual machine fails to execute. Accordingly, the function of the OS of the virtual machine created for the DL application can be eliminated, and thus the capacity of the necessary hardware can be reduced. For instance, the OS may achieve only the function of requesting an OS process and the function of a DL device driver.

<Block Diagram of Application-Executing VM Creating Device **1600**>

FIG. **22** is a block diagram showing an application-executing VM creating device **1600** according to Embodiment 1 of the present invention.

The application-executing VM creating device **1600** shown by FIG. **22** includes a stop code before application execution inserting unit **1601**, a VM creating unit **1602**, a VM executing unit **1603**, and a dedicated VM creating unit **1604**. The application-executing VM creating device **1600** receives a VM source code **1610**, and creates an application-executing VM **1620**. The application-executing VM **1620** is stored as the application-executing VM **1241** into the nonvolatile memory device **1240** in the device **110** or **111**.

The VM source code **1610** includes a source code of an application VMOS and configuration information of a virtual hardware. A string (stop identifier) (e.g. "PRE_APP_EXEC:") is inserted in the source code of the application VMOS immediately before the application VMOS loads, to the memory **1220**, an application which operates on the application VMOS, the string indicating that the application VMOS loads, to the memory **1220**, the application.

The stop code before application execution inserting unit **1601** detects the stop identifier inserted in the VM source code **1610**, and replaces the stop identifier with a notification command (hypercall or hypervisor call) from the application VMOS to the virtualization software **1001**.

The VM creating unit **1602** creates an executable image file of a VM by performing a compilation process and a link process on the VM source code **1610**.

The VM executing unit **1603** has a function equivalent to that of the virtualization software **1001**, and executes the executable image file of the VM. The VM of which executable image file is executed first performs a process up to the notification command which is embedded instead of the stop identifier, and then performs a notification process to the VM executing unit **1603**. Upon receiving the notification, the VM executing unit **1603** terminates the process of the VM.

The dedicated VM creating unit **1604** creates the VM main portion **1311** of the application-executing VM **1620** from a state (data on a memory, a value of a register of a CPU, and so on) of the stopped VM and the executable image file of the VM. Furthermore, the dedicated VM creating unit **1604** generates the header information **1310** and the verification value **1312**, and creates the application-executing VM **1620** by combining the header information **1310** and the verification value **1312**.

The application-executing VM **1620** includes a VM image file stopped in a state immediately before an application is loaded after the application VMOS starts.

It is to be noted that, here, although the stop identifier is inserted immediately before the application is loaded to the memory **1220**, the present invention is not limited to this. For

instance, the stop identifier may be inserted immediately after the application is loaded to the memory **1220**.

Moreover, here, although the stop code before application execution inserting unit **1601** replaces the stop identifier with the notification command (hypercall), the present invention is not limited to this. For example, the stop code before application execution inserting unit **1601** may automatically detect a position at which the file is stopped, by analyzing the VM source code **1610**, and insert the notification command in the detected position. The notification command may be not the hypercall but a breakpoint command or dedicated interrupt command.

As described above, according to Embodiment 1 of the present invention, the universal OS **1011** determines whether the application to be executed is the DL application, when executing the application, and causes the DL application to operate on the virtual machine (application VM) for the DL application, when determining that the application is the DL application. Consequently, it is possible to prevent the DL application from accessing the data used by another application operating on the universal OS **1011** and another DL application.

Moreover, the device **110** dynamically creates the application VM at the time of executing the DL application, and thus the application VM does not always occupy the memory **1220**. Furthermore, the application VMOS is configured to request the virtualization software **1001** to execute the OS process, and thus it is possible to reduce the size of the application VMOS. As a result, it is possible to reduce the size of the memory **1220** used when executing the application VM. Thus, the application distribution system **100** according to Embodiment 1 of the present invention can be applied to cellular phones having scarce resources such as a memory and home electric appliances such as TVs.

Moreover, commonalizing the application VMOS of the virtual machine for executing the DL application makes it possible to reduce an amount of OS data to be stored.

The application VMOS determines whether to (i) request the virtualization software **1001** to execute the OS process or (ii) execute the OS process internally. As a result, processes which become, if performed by the universal OS **1011**, problematic in terms of security are successfully executed inside the application VMOS. Thus, even when the DL application is an attack application, it is possible to prevent the DL application from attacking the universal OS **1011**. Moreover, when the virtualization software **1001** receives the OS process request, the virtualization software **1001** and the application VMOS each determine whether a process which becomes problematic in terms of the security is a process to be originally executed inside the application VMOS. Consequently, in comparison with the case where only the application VMOS makes the determination, it is possible to further increase the security.

As described above, the application distribution system **100** according to Embodiment 1 of the present invention makes it possible to prevent the malicious application and the malicious device driver from leaking and tampering with the information assets. Consequently, the user can safely use the device.

Embodiment 2

Embodiment 2 of the present invention describes a configuration in which a function of causing the universal OS **1011** to execute an OS process of an application VM is not included, as opposed to the configuration described in Embodiment 1 of the present invention.

The following describes configurations and creation processes of the virtualization software **1001** and the universal OS **1011** according to Embodiment 2 of the present invention. It is to be noted that the same reference signs are assigned to the same components and processes as those in Embodiment 1 of the present invention, and descriptions thereof are omitted.

<Configuration of Virtualization Software **1001**>

FIG. **23** is a block diagram showing the virtualization software **1001** according to Embodiment 2 of the present invention.

The virtualization software **1001** shown by FIG. **23** includes the application VM creating unit **1300**, the application-executing VM obtaining unit **1301**, and the VM managing unit **1302**.

Upon receiving, from a virtual machine which operates on the virtualization software **1001**, a request to create a VM (application VM), the application VM creating unit **1300** creates a VM (application VM) for executing DL application from an application-executing VM and a DL application transmitted from the virtual machine. Moreover, the application VM creating unit **1300** requests the VM managing unit **1302** to manage the created virtual machine. Here, unlike Embodiment 1 of the present invention, the application VM creating unit **1300** neither recognizes a parent and a child nor registers the parent and the child in the parent and child relationship managing unit.

It is to be noted that the application-executing VM obtaining unit **1301** and the VM managing unit **1302** are the same as those described in Embodiment 1 of the present invention.

<Configuration of Universal OS **1011**>

FIG. **24** is a block diagram showing the universal OS **1011** according to Embodiment 2 of the present invention.

The universal OS **1011** shown by FIG. **24** includes the application load unit **1400** and the device driver A **1402**. Unlike Embodiment 1 of the present invention, the universal OS **1011** does not receive, from another virtual machine, an OS process request, and thus does not have a necessary function of receiving an OS process request.

The application load unit **1400** and the device driver A **1402** are the same as those described in Embodiment 1 of the present invention.

In Embodiment 2 of the present invention, the application VMOSX **1021** and the application VMOSY **1031** have the same configuration as the universal OS **1011**. It is to be noted that the application load unit **1400** may have the same configuration as the universal OS **1011**, that in the configuration shown by FIG. **17**A, the application load unit **1400** may not include the determining unit **1411** and the VM creation requesting unit **1413**, and may cause the load unit **1412** to load, after the application obtaining unit **1410** obtains an application, the application on an application VMOS, and that the application load unit **1400** may have a configuration in which an application operating on an application VMOS is prohibited from starting another application.

<Application VM Creation Process>

An application VM creation process according to Embodiment 2 of the present invention is largely the same as the application VM creation process (FIG. **20**) according to Embodiment 1 of the present invention.

However, the virtualization software **1001** according to Embodiment 2 of the present invention has no function of controlling an OS process request from an application VM, and thus does not register the parent and child relationship in step **S1104**. As a result, the application VM creating unit **1300** creates the application VM from the application-executing VM and the DL application (**S1102** and **S1103**), registers the

created application VM in the VM managing unit **1302**, and then requests the VM managing unit **1302** to execute the created application VM. The requested VM managing unit **1302** executes the application VM (S**1105**).

It is to be noted that processes other than the above are the same as those in Embodiment 1 of the present invention.

As described above, according to Embodiment 2 of the present invention, the universal OS **1011** determines whether the application to be executed is the DL application, when executing the application, and causes the DL application to operate on the virtual machine (application VM) for the DL application, when determining that the application is the DL application. Thus, the application distribution system **100** according to Embodiment 2 of the present invention makes it possible to prevent the DL application from accessing the data used by the application operating on the universal OS **1011** or another DL application.

As described above, the application distribution system **100** according to Embodiment 2 of the present invention makes it possible to prevent the malicious application and the malicious device driver from leaking and tampering with the information assets. Consequently, the user can safely use the device.

Embodiment 3

Embodiment 3 of the present invention describes a configuration in which a function of creating a virtual machine is not included, as opposed to the configuration described in Embodiment 1 of the present invention.

The following describes configurations and creation processes of the virtualization software **1001** and the universal OS **1011** according to Embodiment 3 of the present invention. It is to be noted that the same reference signs are assigned to the same components and processes as those in Embodiment 1 of the present invention, and descriptions thereof are omitted.

<Configuration of Virtualization Software **1001**>

FIG. **25** is a block diagram showing the virtualization software **1001** according to Embodiment 3 of the present invention.

The virtualization software **1001** shown by FIG. **25** includes the VM managing unit **1302**, the OS process request control unit **1303**, the parent and child relationship managing unit **1304**, and the policy managing unit **1305**.

It is to be noted that the VM managing unit **1302**, the OS process request control unit **1303**, the parent and child relationship managing unit **1304**, and the policy managing unit **1305** are the same as those described in Embodiment 1 of the present invention.

<Configuration of Universal OS **1011**>

FIG. **26** is a block diagram showing the universal OS **1011** according to Embodiment 3 of the present invention.

The universal OS **1011** shown by FIG. **26** includes the application VM OS process receiving unit **1401** and the device driver A **1402**.

The application VM OS process receiving unit **1401** and the device driver A **1402** are the same as those described in Embodiment 1 of the present invention.

It is to be noted that although the present invention has been described based on the embodiments, it goes without saying that the present invention is not limited to the embodiments. The present invention includes the following cases.

(1) Although the DL application according to the embodiments is downloaded from the application distribution server **120**, the present invention is not limited to this. For instance, the DL application may be an application installed from an apparatus for development or a PC connected through a USB, or may be originally installed at the time of shipment of the device **110**.

(2) The software configuration of each of the devices **110** and **111** according to the embodiments may not include the virtual machine **1005** including the RTOS **1041**, or may include virtual machines **1002** each of which includes the universal OS **1011** or virtual machines **1005** each of which includes the RTOS **1041**. Moreover, the software configuration may include a virtual machine which does not include an OS, or a virtual machine on which an application involving an OS function operates. Furthermore, these virtual machines may request the virtualization software **1001** to create an application VM. Here, each of the virtual machines is registered as a separate parent in the parent and child relationship managing unit **1304**.

(3) Although the application VM according to the embodiments is loaded to the memory **1220** at the time of executing the DL application, and is executed, the present invention is not limited to this. For example, the virtualization software **1001** may load only the application-executing VM **1241** to the memory **1220** prior to the execution of the DL application, and load the DL application to the memory **1220** at the time of executing the DL application. Moreover, the virtualization software **1001** may load the application-executing VM **1241** and the DL application to the memory **1220** before the execution of the DL application.

(4) Although the application-executing VM **1241** according to the embodiments includes the VM image file stopped, using the application-executing VM creating device **1600**, in a state immediately before the application is loaded after the application VMOS starts, the present invention is not limited to this. For instance, the application-executing VM **1241** may include a VM image file in a state before the application VMOS starts. Here, the application VMOS may start for each DL application, or an application VM stopped in a state immediately before the application is loaded may be started in advance, the application VM stopped in the state immediately before the application is loaded may be copied at the time of executing the DL application, and the copied application VM may execute the DL application.

(5) Each of the above devices is specifically a computer system including, for instance, a microprocessor, a ROM, a RMA, a hard disk unit, a display unit, a keyboard, and a mouse. A computer program is stored in the RAM or the hard disk unit. The microprocessor operates according to the computer program, so that each device performs a corresponding function. Here, in order to perform a predetermined function, the computer program is programmed by combining instruction codes each indicating an instruction for a computer.

(6) Part or all of the elements included in each device may be included in one system LSI (Large Scale Integration). The system LSI is a super-multifunctional LSI manufactured by integrating the elements on one chip, and is specifically a computer system including a microprocessor, a ROM, a RAM, and so on. A computer program is stored in the RAM. The microprocessor operates according to the computer program, so that the system LSI performs its function.

Moreover, the elements included in each device may be integrated into individual chips, or into a single chip so as to include part or all of the elements.

Here, although an integrated circuit is referred to as the system LSI, the integrated circuit may also be referred to as an IC, an LSI, a super LSI, or an ultra LSI. In addition, a circuit integration method is not limited to the LSI, and may be realized with a dedicated circuit or a general-purpose processor. FPGA (Field Programmable Gate Array) that can be

programmed after the manufacture of the LSI or a reconfigurable processor which can reconfigure connection or setting of circuit cells in the LSI may be used.

Additionally, if a new circuit integration technique is introduced in place of the LSI along with development in semiconductor technology or other derivative technology, it is obvious that the technique may be used for integrating functional blocks. There is a possibility of applying biotechnology and the like.

(7) Part or all of the elements included in each device may be included in an IC card detachable to each device or in a stand-alone module. The IC card or the module is a computer system including a microprocessor, a ROM, a RAM, and so on. The IC card or the module may include the super-multi-functional LSI. The microprocessor operates according to a computer program, so that the IC card or the module performs its function. The IC card or the module may have tamper-resistance.

(8) The present invention may be any of the above methods. Moreover, the present invention may be a computer program which causes a computer to perform these methods or a digital signal included in the computer program.

Furthermore, in the present invention, the computer program or the digital signal may be recorded on a computer-readable recording medium such as a flexible disk, a hard disk, a CD-ROM, an MO, a DVD, a DVD-ROM, a DVD-RAM, a BD (Blu-ray Disc), and a semiconductor memory. In addition, the present invention may be the digital signal recorded on these recording media.

Moreover, in the present invention, the computer program or the digital signal may be transmitted via an electric telecommunication line, a wireless or wired telecommunication line, a network represented by the Internet, data broadcasting, or the like.

Furthermore, the present invention may be a computer system including a microprocessor and a memory. The computer program may be stored in the memory, and the microprocessor may operate according to the computer program.

Moreover, by recording the program or the digital signal on the recording medium to transfer it, or by transferring the program or the digital signal via the network or the like, the present invention may be implemented on another independent computer system.

(9) The embodiments and the modifications may be combined.

INDUSTRIAL APPLICABILITY

The present invention can be applied to information processing devices which use downloaded applications and device drivers. In addition, the present invention is useful to, for example, cellular phones and home electric appliances such as televisions which include the information processing devices.

REFERENCE SIGNS LIST

10 Hardware
20, **1001** Virtualization software
30, **40**, **70**, **80**, **1002**, **1003**, **1004**, **1005** Virtual machine
60 VMM
72, **1315** OS
90 VM creating device
100 Application distribution system
110, **111** Device
120 Application distribution server
130 Apparatus for development
1000 Normal software execution environment (normal environment)
1010, **1020**, **1030**, **1040**, **1316** Virtual hardware
1011 Universal OS
1012 Download control application
1013 Application A
1014 Application B
1021 Application VMOSX
1022, **1242** DL application X
1031 Application VMOSY
1032, **1243** DL application Y
1041 RTOS
1042 Phone call software
1100 Secure software execution environment (secure environment)
1101 Secure OS
1102 Secure boot unit
1200 System LSI
1201 CPU
1202 IPL (Initial Program Loader)
1203 Execution environment switching unit
1204 Internal secure memory
1220 Memory
1240 Nonvolatile memory device
1241, **1620** Application-executing VM
1300 Application VM creating unit
1301 Application-executing VM obtaining unit
1302 VM managing unit
1303 OS process request control unit
1304 Parent and child relationship managing unit
1305 Policy managing unit
1310 Header information
1311 VM main portion
1312 Verification value
1350 Virtual machine management table
1360 Parent and child relationship management
1370, **1371** Policy table
1400 Application load unit
1401 Application VM OS process receiving unit
1402 Device driver A
1410 Application obtaining unit
1411 Determining unit
1412 Load unit
1413 VM creation requesting unit
1500 OS process requesting unit
1501 Device driver B
1510 OS process receiving unit
1511 Request determining unit
1512 Internal processing unit
1513 Requesting unit
1600 Application-executing VM creating device
1601 Stop code before application execution inserting unit
1602 VM creating unit
1603 VM executing unit
1604 Dedicated VM creating unit
1610 VM source code
2000 Application holding unit
2001 Application reception processing unit
2002 Application transmission processing unit
3000 Package generating unit
3001 Configuration file generating unit
3002 Key pair holding unit
3003 Key pair generating unit
3004 Debug processing unit
3005 Upload processing unit
3100 Compiler
3101 Linker

3102 Package generation tool
3110 Source code
3120 Download package
3130 Private key
3131, **3204** Public key certificate
3132, **3202** Configuration file
3200 Application
3201 Device driver
3203 Application signature list

The invention claimed is:

1. An information processing device having a plurality of virtual machines, said information processing device comprising:

a processor; and

a virtual machine managing unit configured to manage, using the processor, the virtual machines,

wherein said virtual machine managing unit includes an application virtual machine (VM) creating unit configured to create a virtual machine for executing a program,

a first virtual machine includes first virtual hardware and a first operating system (OS) and determines whether a first program is to be executed on the first virtual machine or to be executed on a second virtual machine, the first virtual machine being one of the virtual machines, and the first program being executable on the first virtual machine,

said application VM creating unit is configured to create the second virtual machine, when the first virtual machine determines that the first program is to be executed on the second virtual machine,

when the first program is a program downloaded from another device, the first virtual machine determines that the first program is to be executed on the second virtual machine,

the second virtual machine includes second virtual hardware and a second OS having only part of functions of the first OS, and executes the first program,

the second virtual machine includes an OS process requesting unit configured to, when an OS process inexecutable on the second OS is requested by the first program, send, to said virtual machine managing unit, an OS process request for requesting the first virtual machine to execute the OS process,

said virtual machine managing unit further includes:

an OS process request control unit configured to request the first virtual machine to execute the OS process, when said virtual machine managing unit receives the OS process request from the second virtual machine; and

a policy managing unit configured to hold information indicating, among functions of said information processing device, a function of prohibiting the second virtual machine from requesting the first virtual machine to execute the OS process, and determine, based on the information, whether or not it is possible for the second virtual machine to request the first virtual machine to execute the OS process,

said OS process request control unit is configured to request the first virtual machine to execute the OS process, when said policy managing unit determines that it is possible for the second virtual machine to request the first virtual machine to execute the OS process,

said OS process requesting unit is configured to determine whether or not the OS process requested by the first program is executable by a device driver software program included in the second virtual machine,

when the OS process requested by the first program is executable by the device driver software program, the OS process requested by the first program is executed within the second virtual machine, and

when the OS process requested by the first program is not executable by the device driver software program, the first virtual machine is requested to execute the OS process requested by the first program.

2. The information processing device according to claim **1**,

wherein when the first program includes a device driver software program obtained from another device, the first virtual machine determines that the first program is to be executed on the second virtual machine.

3. The information processing device according to claim **2**, further comprising

a storage unit configured to store an OS program for VM,

wherein the first virtual machine further determines whether a second program is to be executed on the first virtual machine or to be executed on a third virtual machine, the second program being different from the first program and executable on the first virtual machine, and

said application VM creating unit is configured to (i) create the third virtual machine, when the first virtual machine determines that the second program is to be executed on the third virtual machine, and (ii) create, using the OS program for VM, an operating system for the second virtual machine and an operating system for the third virtual machine.

4. The information processing device according to claim **3**,

wherein the second virtual machine includes a VM image file stopped in a state immediately before a program is loaded after an operating system for a virtual machine starts.

5. The information processing device according to claim **1**, further comprising

a storage unit configured to store an OS program for VM,

wherein the first virtual machine further determines whether a second program is to be executed on the first virtual machine or to be executed on a third virtual machine, the second program being different from the first program and executable on the first virtual machine, and

said application VM creating unit is configured to (i) create the third virtual machine, when the first virtual machine determines that the second program is to be executed on the third virtual machine, and (ii) create, using the OS program for VM, an operating system for the second virtual machine and an operating system for the third virtual machine.

6. The information processing device according to claim **5**,

wherein the second virtual machine includes a VM image file stopped in a state immediately before a program is loaded after an operating system for a virtual machine starts.

7. The information processing device according to claim **1**,

wherein said virtual machine managing unit further includes a parent and child relationship managing unit configured to manage a parent and child relationship of the virtual machines,

said parent and child relationship managing unit is configured to manage a parent and child relationship in which the first virtual machine that requests the creation of the second virtual machine is a parent and the second virtual machine created according to the request is a child, and

said OS process request control unit is configured to request the first virtual machine to execute the OS process, when said virtual machine managing unit receives the OS process request from the second virtual machine,

the first virtual machine being managed as the parent of the second virtual machine.

8. The information processing device according to claim **1**, wherein said OS process requesting unit is configured to (i) determine that the second virtual machine executes the OS process, when the first program includes the device driver software program obtained from the other device and the device driver software program can execute the OS process, and (ii) send the OS process request to said virtual machine managing unit when the device driver software program cannot execute the OS process.

9. The information processing device according to claim **1**, wherein the OS process request control unit is configured to request the first virtual machine to execute the OS process, using a callback function, dedicated interruption, or a system call.

10. An application distribution system which distributes a program via a network, said application distribution system comprising:

said information processing device according to claim **1**; and

an application distribution server,

wherein said application distribution server includes:

an application holding unit configured to hold a program to be distributed; and

an application transmission processing unit configured to transmit the program to said information processing device, and

when the first program is the program transmitted by said application transmission processing unit, the first virtual machine determines that the first program is to be executed on the second virtual machine.

11. A virtual machine creation method performed by an information processing device which has a plurality of virtual machines and includes a virtual machine managing unit that manages the virtual machines, said virtual machine creation method comprising:

creating a virtual machine for executing a program, said creating being performed by the virtual machine managing unit;

determining whether a first program is to be executed on a first virtual machine including first virtual hardware and a first operating system (OS) or to be executed on a second virtual machine, said determining being performed by the first virtual machine, the first virtual machine being one of the virtual machines, and the first program being executable on the first virtual machine,

wherein when the first virtual machine determines that the first program is to be executed on the second virtual machine, the second virtual machine for executing the first program is created in said creating,

said virtual machine creation method further comprising:

determining that the first program is to be executed on the second virtual machine, when the first program is a program downloaded from another device, the second virtual machine (i) including second virtual hardware and a second OS having only part of the function of the first OS and (ii) executing the first program, said determining being performed by the first virtual machine;

sending, to the virtual machine managing unit when an OS process inexecutable on the second OS is requested by the first program, an OS process request for requesting the first virtual machine to execute the OS process, said sending being performed by the second virtual machine;

requesting the first virtual machine to execute the OS process, when the virtual machine managing unit receives the OS process request from the second virtual machine, said requesting being performed by the virtual machine managing unit; and

determining, based on information indicating, among functions of the information processing device, a function prohibiting the second virtual machine from requesting the first virtual machine to execute the OS process, whether or not it is possible for the second virtual machine to request the first virtual machine to execute the OS process, the information being held by the information processing device, and said determining of whether or not it is possible being performed by the virtual machine managing unit,

when it is determined that it is possible for the second virtual machine to request the first virtual machine to execute the OS process, the first virtual machine is requested to execute the OS process in said requesting,

said requesting includes determining whether or not the OS process requested by the first program is executable by a device driver software program included in the second virtual machine,

when the OS process requested by the first program is executable by the device driver software program, the OS process requested by the first program is executed within the second virtual machine, and

when the OS process requested by the first program is not executable by the device driver software program, the first virtual machine is requested to execute the OS process requested by the first program.

12. A non-transitory computer-readable recording medium for use in a computer, the recording medium having a computer program recorded thereon for causing the computer to execute the virtual machine creation method according to claim **11**.

13. A semiconductor integrated circuit having a plurality of virtual machines, said semiconductor integrated circuit comprising

a virtual machine managing unit configured to manage the virtual machines,

wherein said virtual machine managing unit includes an application virtual machine (VM) creating unit configured to create a virtual machine for executing a program,

a first virtual machine includes first virtual hardware and a first operating system (OS), and determines whether a first program is to be executed on the first virtual machine or to be executed on a second virtual machine, the first program being executable on the first virtual machine, and the first virtual machine being one of the virtual machines,

said application VM creating unit is configured to create the second virtual machine, when the first virtual machine determines that the first program is to be executed on the second virtual machine,

when the first program is a program downloaded from another device, the first virtual machine determines that the first program is to be executed on the second virtual machine,

the second virtual machine includes second virtual hardware and a second OS having only part of functions of the first OS, and executes the first program,

the second virtual machine includes an OS process requesting unit configured to, when an OS process inexecutable on the second OS is requested by the first program, send, to said virtual machine managing unit, an OS process request for requesting the first virtual machine to execute the OS process,

said virtual machine managing unit further includes:

an OS process request control unit configured to request the first virtual machine to execute the OS process, when said virtual machine managing unit receives the OS process request from the second virtual machine; and

a policy managing unit configured to hold information indicating, among functions of said information processing device, a function of prohibiting the second virtual machine from requesting the first virtual machine to execute the OS process, and determine, based on the information, whether or not it is possible for the second virtual machine to request the first virtual machine to execute the OS process,

said OS process request control unit is configured to request the first virtual machine to execute the OS process, when said policy managing unit determines that it is possible for the second virtual machine to request the first virtual machine to execute the OS process,

said OS process requesting unit is configured to determine whether or not the OS process requested by the first program is executable by a device driver software program included in the second virtual machine,

when the OS process requested by the first program is executable by the device driver software program, the OS process requested by the first program is executed within the second virtual machine, and

when the OS process requested by the first program is not executable by the device driver software program, the first virtual machine is requested to execute the OS process requested by the first program.

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